Studies on Performance of Pin-Fin Heat Sink

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***Abstract*:- The primary objective of the present study is to conduct fluid flow and heat transfer measurements on pin-fin arrays to investigate the flow and heat transfer characteristics. The material of the base plate and pin-fin are of duralumin (2024) used. An experimental setup fabricated with necessary instrumentation to measure pressure, flow and temperature. Air was the medium used in this study. Pin-fins arranged were in in-line and staggered manner. The results of the in-line configurations were also compared with the results of the staggered arrangements for pin-fins.**

Keywords: Pin-fin, duct flow, forced convection, heat exchangers, performance.

1. INTRODUCTION

The heat transfer community has relentlessly striven to achieve high heat transfer coefficients, *albeit*, with minimal pressure drop penalties. It is very well known that increase of velocity augments the heat transfer coefficients, and at the same time induces considerable penalties by way of increased pumping power. Enhancement of heat transfer, as a consequence, has been one of the favorite topics of investigation of thermal engineers [1].

In all the thermal management systems developed so far, heat sinks are probably the most extensively used due to their ease of use, fabrication and heat transfer capability. Researchers often have introduced efficient ideas such as pin-fin structures and increased surface density for reducing the thermal resistance of the cooling system [2]. A heat sink can be defined as a device that dissipates heat from any system resulting lower temperature difference and thermal resistance. The primary motive of using a heat sink can be classified into: 1) improving the thermal management of system by increasing the heat dissipation area available and 2) increasing the functionality and reliability of a system (e.g.; electronic device). Among all the ideas proposed over the years, the pin-fin heat sink is the most promising one due to its capability of dissipating a high heat flux. The advantages of the pin-fin heat sinks include low thermal resistance, high heat transfer efficiency, high heat transfer area density, compactness and its suitability for use with different coolants with little alteration in the coolant loop.

Various types of heat-exchanger fins, ranging from relatively simple shapes, such as rectangular, cylindrical, annular, tapered or pin fins, to a combination of different geometries, have been used [3]. These fins may protrude from either a rectangular or cylindrical base. One of the commonly used heat exchanger fins are the pin fins. A pin fin is a cylinder or other shaped element attached perpendicularly to a wall, with the transfer fluid passing in cross-flow over the element. Some of the parameters characterizing the pin fins are shape, height (H) and diameter (d) and height-to-diameter ratio (H/d). Other pertinent parameters are distances between the fins in the span wise (S_x) and stream wise (S_y) directions and clearance ratio (C/H). There have been many investigations of the heat transfer and pressure drop in channels with pin fins, but are usually limited to pin fins with circular cross section. From the previous investigations, it is well known that the pin-fin arrays dissipate higher heat transfer than plain channels. However, the increase in heat transfer is always accompanied by a substantial increase in pressure loss. Therefore, in most applications of pin fins, both the heat transfer and pressure loss characteristics must be considered [4]. On the other hand, the pin fins with various cross sections have different heat transfer and flow resistance characteristics, though it is evident that circular pin fins are the best for heat transfer, friction and performance. Therefore, it is essential to investigate pin fins of various cross sections in order to enhance the heat transfer and decrease the flow resistance. It is the aim of this study to investigate the heat transfer, pressure and performance characteristics for the in-line and staggered pin-fin arrays attached on a flat surface in a rectangular channel by considering various geometric and flow parameters [5].

2. EXPERIMENTAL SET-UP

This chapter deals the fabrication of pin-fins and setup to carry out experiments with a wind tunnel. It is customary to carry out forced convection experiments in wind tunnel to investigate performance of heat transfer test modules. Subsequent sections are devoted to discuss these in detail [6].

2.1 Pin-fin assembly

The pin-fin arrays considered for this investigation are having circular, square and diamond cross-section pin-fins respectively having dimensions; diameter (d) 10 mm with height (H) 90 mm and fin-size 9.2 x 9.2 mm^2 of height (H) 7.68 mm (square and diamond) are protruding vertically upwards from a 250 mm x 145 mm horizontal rectangular base having thickness 25.4 mm as shown in F.g.3. The number of fins can be varied in accordance with the fin spacing [7]. The maximum and minimum numbers of pin-fins used in this investigation are 220 and 22 respectively.

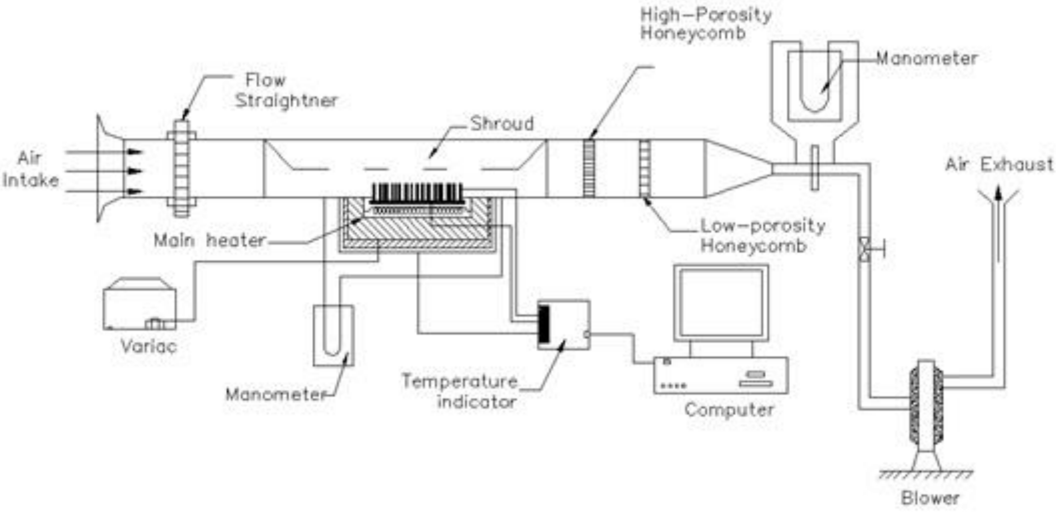

Fig.1 Schematic of the experimental set-up

2.2 Wind-tunnel

The heated air from the pin fin assembly was passed through an insulated chamber, where mixing was accomplished by two cardboard honeycombs mounted perpendicular to the flow stream, one being of relatively low porosity and the other of higher porosity. The latter was situated upstream of the former [8]. At the exhaust end of the duct, a gradual area-contraction section attached is used to connect a single-speed, single-stage blower (via G.I. pipe). Blower was capable of providing a maximum flow rate of 0.242 kg/s, and is preceded by a butterfly throttle control valve.

3. RESULTS AND DISCUSSIONS

3.1 Effect of clearance ratio (C/H)

The effect of clearance ratio on heat transfer rate for the range of Reynolds number covered in the experiments is illustrated in the figure.4. It appears that the heat transfer rate increases monotonically with Reynolds number for all C/H values. Also, that for the smallest value of C/H the largest heat transfer is observed and this enhancement of heat transfer is achieved by increasing the compactness of the heat exchanger (ie; restricting the free flow of air).

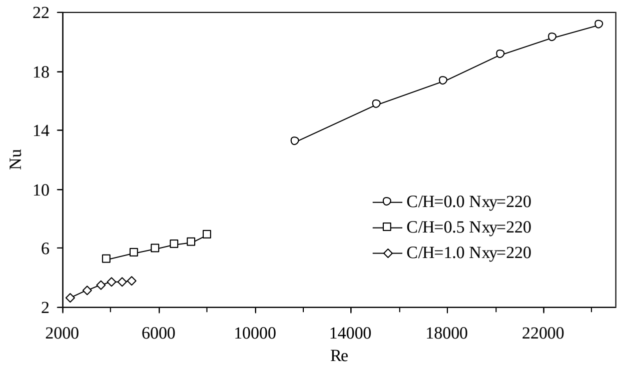

Fig.2 Plot of Nusselt number *vs* Reynolds number for $S_x = S_y = 12$ (cylinder)

This trend is reported by earlier investigators (Jubran *et al.* 1993; Tahat *et al.*, 1994; Tahat *et al.*; 2000, Kadir *et al.* 2001; Sara, 2003). The maximum heat transfer occurs at lower inter fin distance in the span-wise and stream-wise direction at the same time, the pressure drop across the pin-fin array was so large that the flow was obstructed by the fins.

3.2 Effect of pin-fin surface area / number of fins

Enhancement of heat transfer is normally achieved by many techniques and here it is attained by minimizing inter-fin-distance in both directions. As the pin-fin surface area is large and for lower S_y/d values the fluid passes in stream-wise direction with less effect. This is because the pin-fins beyond the first row of an array are in the turbulent wakes of the upstream pin fins [10]. For moderate value of S_y convection coefficients associated with downstream rows are enhanced by the resulting turbulence of the flow. However, for very small values of S_y upstream rows, in effect, shield downstream rows (wake effect) and the rate of heat transfer is reduced. That is the preferred flow path is in lanes between the pin-fins so much of the pin-fin surface area is not exposed to the main flow.

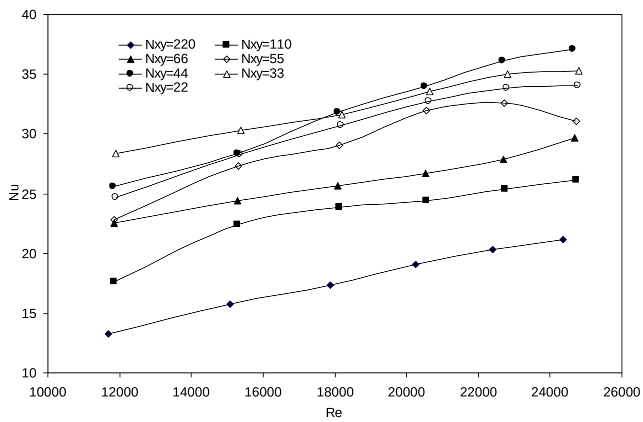

Fig.3 Plot of Nu *vs* Reynolds number for C/H=0, S_x= 12 (cylinder)

The maximum heat transfer/ Nusselt number occurs at lower inter-fin distance in the span-wise and stream-wise direction at the same time, the pressure drop across the pin-fin array was so large that the flow was obstructed by the fins. The same effect is also evidenced from Fig.2 and 3 that are plotted for Nusselt number against Reynols number.

4. CONCLUSIONS

Experimental investigation on fin-pin assembly was carried out in a wind tunnel setup to study the heat transfer characteristics. The conclusions arrived from present study are enumerated.

- The variation in spacing on both span-wise and stream-wise directions have effect on Nusselt number.
- The change in Nusselt number is more rapid for stream-wise direction (S_y) than that for the span-wise direction (S_x).
- For certain packing density of the pin-fin (or N_{xy}) there exist maximum value of Nusselt number.
- The average Nusselt number increases monotonically with increasing Reynolds number.
- The average Nusselt number increase with decreasing clearance ratio monotonically and whereas inter-fin distance ratio effect on Nusselt number is not monotonous.
- There exist a optimum value of inter-fin distance ratio (i.e.; spacing).
- For a given Reynolds number, the pin-fin array with particular inter-fin distance or number of pin-fins gives higher performance than those at other values

Nomenclature

- A area, m^2
- C clearance between fin tip and the roof, mm
- Cp specific heat of air, J/kg K
- d diameter of the pin-fin, mm
- f friction factor
- G mass flux, kg/m^2s
- H height of the pin-fin, mm
- k thermal conductivity, W/m K
- L length of the base plate, mm
- m mass flow rate of air, kg/s
- N number of pin-fin
- Nu Nusselt number
- Q heat transfer rate, W
- Re Reynolds number
- S spacing, mm
- t temperature,o C
- T temperature, K
- W width of the base plate, mm
- x, y, z set of Cartesian coordinates
- Δp overall pressure drop along the array, N/m^2
- μ dynamic viscosity, N s/m^2
- ρ density, kg/m^3
- Subscripts
- a air
- b base plate
- conv convection
- ff free flow
- in inlet condition
- rad radiation
- tot total
- ts total surface
- x, y directions

5. REFERENCE

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