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Investigation on Fluid Flow and Heat Transfer Characteristics of Pin-Fin Arrays

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Abstract: This is article presents the results of an experimental 'investigation on fluid flow and heat transfer characteristics of pin-fin arrays'. In the past few decades, this topic has generated a keen interest because of its wide applications to cooling of microelectronic devices and turbine blade cooling. An overview of literature available on pin-fin array is given, based on which the problem has been identified. The study covers specifically the heat transfer, friction characteristics of convective heat transfer through a rectangular channel with cylindrical and square (with and without perforation) and diamond cross-section pin-fins attached over a rectangular duralumin flat surface with flow of air.

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. As a consequence, enhancement of heat transfer has been one of the favourite topics of investigation of thermal engineers. Those features are often encountered in the domain of micro-electro- mechanical systems (MEMS), wherein the surface areas available for heat transfer are very small. Removing large quantities of heat from small surface areas is invariably the major task in the thermal management of very and ultra large scale integration (VLSI and ULSI) systems widely applied in electronic equipment. Significant progresses in miniaturization of electronic packages achieved in the last few years have guided thermal engineers towards innovation of novel cooling technologies. It is fair to realize that thermal design not been able to keep pace with the strides in the electronic system design. Earlier studies on pin-fin arrays may be found in literature;(1,2,3,4&11,12)

I. PRESENT STUDY

In the present work, the heat transfer and friction characteristics of pin-fin arrays (cylinder, square, diamond) are experimentally investigated. Employing a finned heating surface kept at a constant temperature at 50^{O}C in a rectangular channel and passing air as working fluid through it. The position of the pin-fins attached on the surface was arranged either in-line or staggered manner. The parameters in this investigation are Reynolds number (range 2000-25000) depending up on the pin-fin diameter, spacing in the span-wise (S_X) and stream-wise(S_Y) directions and clearance ratio (C/H).

II. EXPERIMENTAL SETUP

The experimental set up used in the current study is shown in the figures 1 to 3. The main body of the rectangular cross-sectioned wind-tunnel duct (Figure 3) was manufactured from wood and was 2-m long with a constant internal width of 145 mm. However, the uniform vertical height (max. 18 cm) of the duct, and hence, the duct's cross- sectional area, could be varied. Different duct heights were obtained by means of an adjustable horizontal roof (or shroud). Approximately halfway along the length of the wind-tunnel duct was the test' section. The roof and side walls of this wind tunnel were made of 20 mm thick wood. A bell-mouth section was fitted at the entrance of the wind- tunnel duct, followed by a low-porosity cardboard honeycomb

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flow straightner. The exhaust air from the pin-fin assembly was passed through an insulated chamber where mixing was accomplished by two cardboard honeycombs, one being of relatively low porosity and the other of higher porosity. The latter was situated upstream of the former. The two honeycombs were mounted perpendicular to the flow. At the exhaust end of the duct, a gradual area-contraction section was attached. It was connected, via a plastic pipe, to a single-speed, single-stage blower, and preceded by a throttle control valve. A differential manometer was employed to measure the pressure drop across an orifice plate to indicate airflow speeds. The wind tunnel was operated in the suction mode; i.e., the blower inducts atmospheric air through the fin assembly and the test section via the bell- mouthed entrance section, with the blower and motor assembly on the exhaust side of the system. This is to avoid the air stream being heated by the blower operation prior to heat exchanger assembly: this would thereby, have reduced the cooling period capability of the air. The overall pressure drop through the heat exchanger was obtained via static-pressure taps located in the base plate.

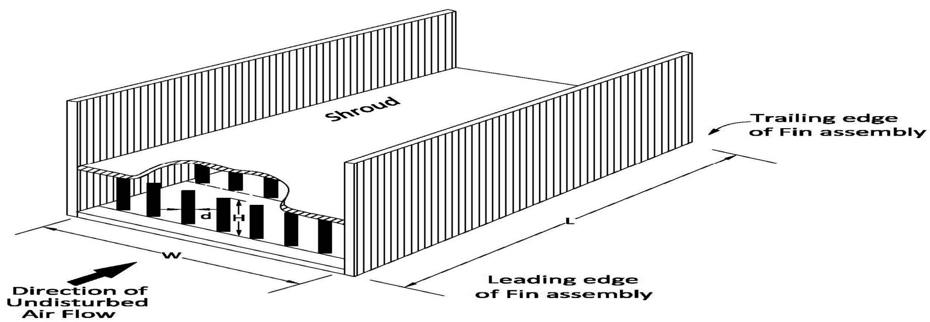

Fig. 1: Ensemble of pin-fin with shroud

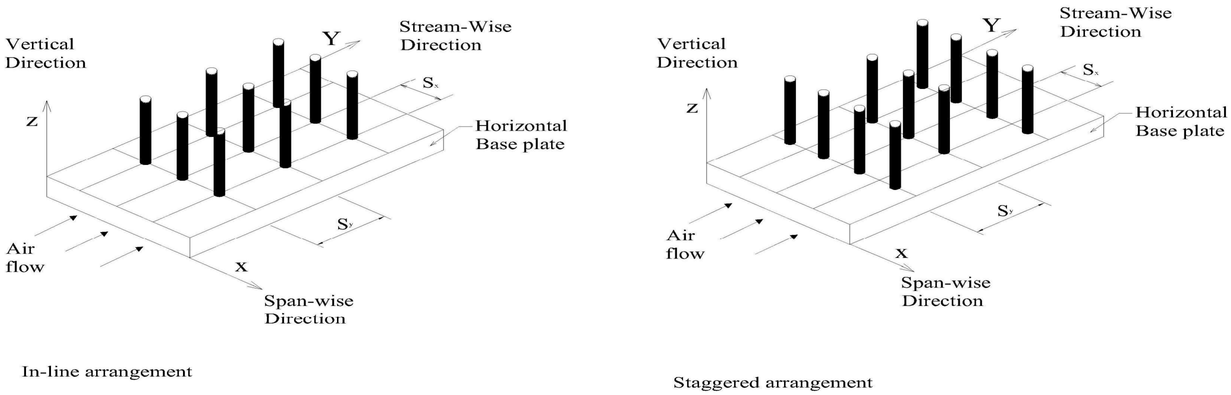

Fig. 2: Pin-fin assembly (a) Inline (b) Staggere

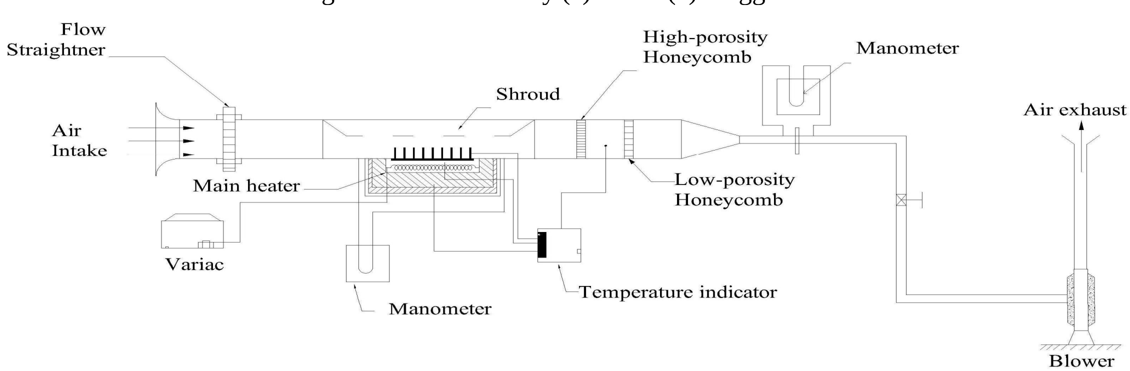

Fig. 3: Experimental setup

III. EXPERIMENT

In the first phase, experiments conducted on in- line and staggered arrays by varying the spacings: i) S_X from 1.2 cm to 9.6 cm and ii) S_Y from 1.2 cm to 22.8 cm. In all the cases, the Reynolds number varied from 2000 to 25000 along with C/H from 0.0 to 1.0. In the second phase of this study, a novel technique used is to increase the heat transfer enhancement by introducing holes (perforations) in the pin-fins parallel to flow direction. The heat transfer increase and pressure drop decrease are in view of surface area increase by perforations causing flow resistance small.

IV. RESULTS

Some typical and salient pin-fin performance characteristics are given here

A. Clearance Ratio Effect on Heat Transfer

The clearance ratio effect 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. In addition, that for the smallest value of C/H the largest heat transfer is observed and this enhancement of heat transfer (Fig. 5) is achieved by increasing the compactness of the heat exchanger (ie; restricting the free flow of air). This trend is reported earlier investigators. Friction or pressure drop results are shown in Figure 6.

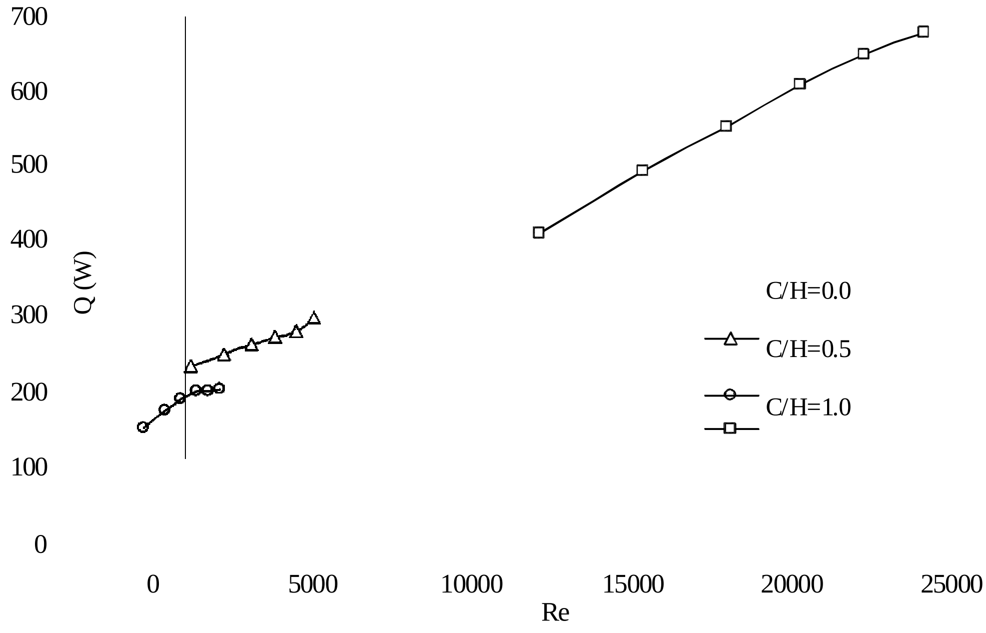

Fig. 4: Plot of Heat Transfer *versus* Reynolds Number for C/H=0.0, S_Y/d =1.2 and S_X/d=1.2

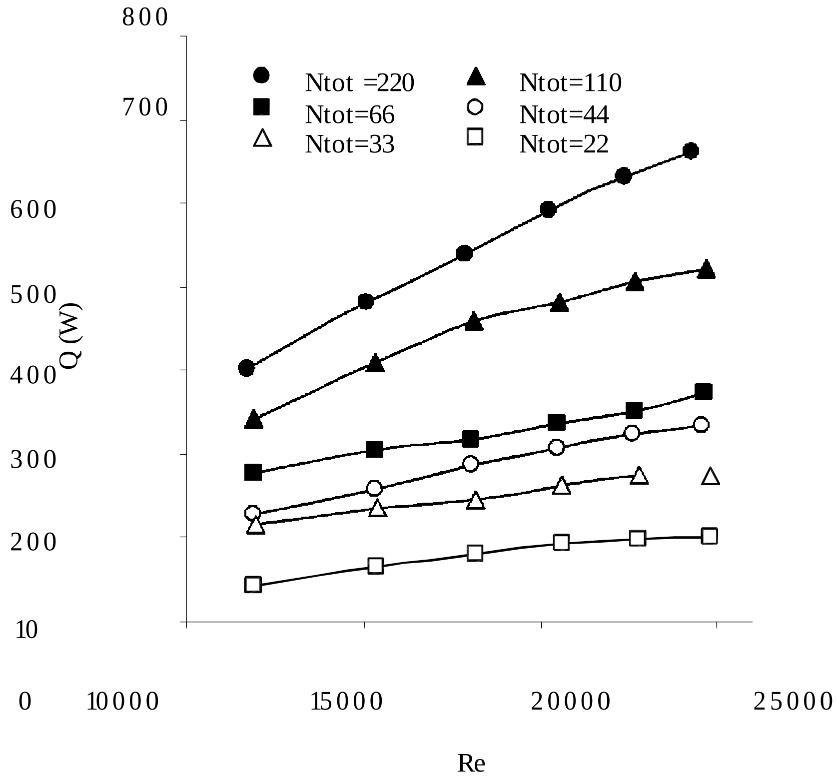

Fig. 5: Variation of the Heat Transfer with Reynolds Number

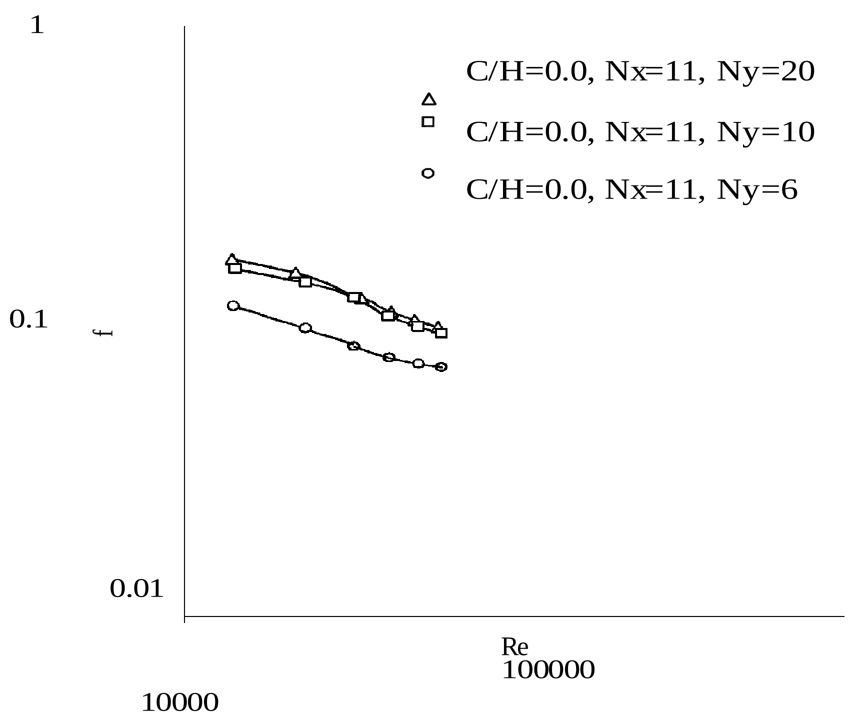

Fig. 6: Plot of Friction Factor *versus* Reynolds number for C/H=0.0, and S_X/d=1.2

An empirical Correlation for Nusselt Number (Nu) involving Reynolds Number (Re), Spacing ratio in the span wise and stream wise direction of the form is developed:

$$Nu = a\,(Re)^{b}\,(S_x / W)^{c}\,(S_y / L)^{d}$$

V. CONCLUSION

The present study complements the prognosis of the previous studies in the area of pin-fin arrays and gives new directions through which the behavior in pin-fin arrays could be explained. The detailed results on heat transfer and pressure drop values generated here can be used for computations.

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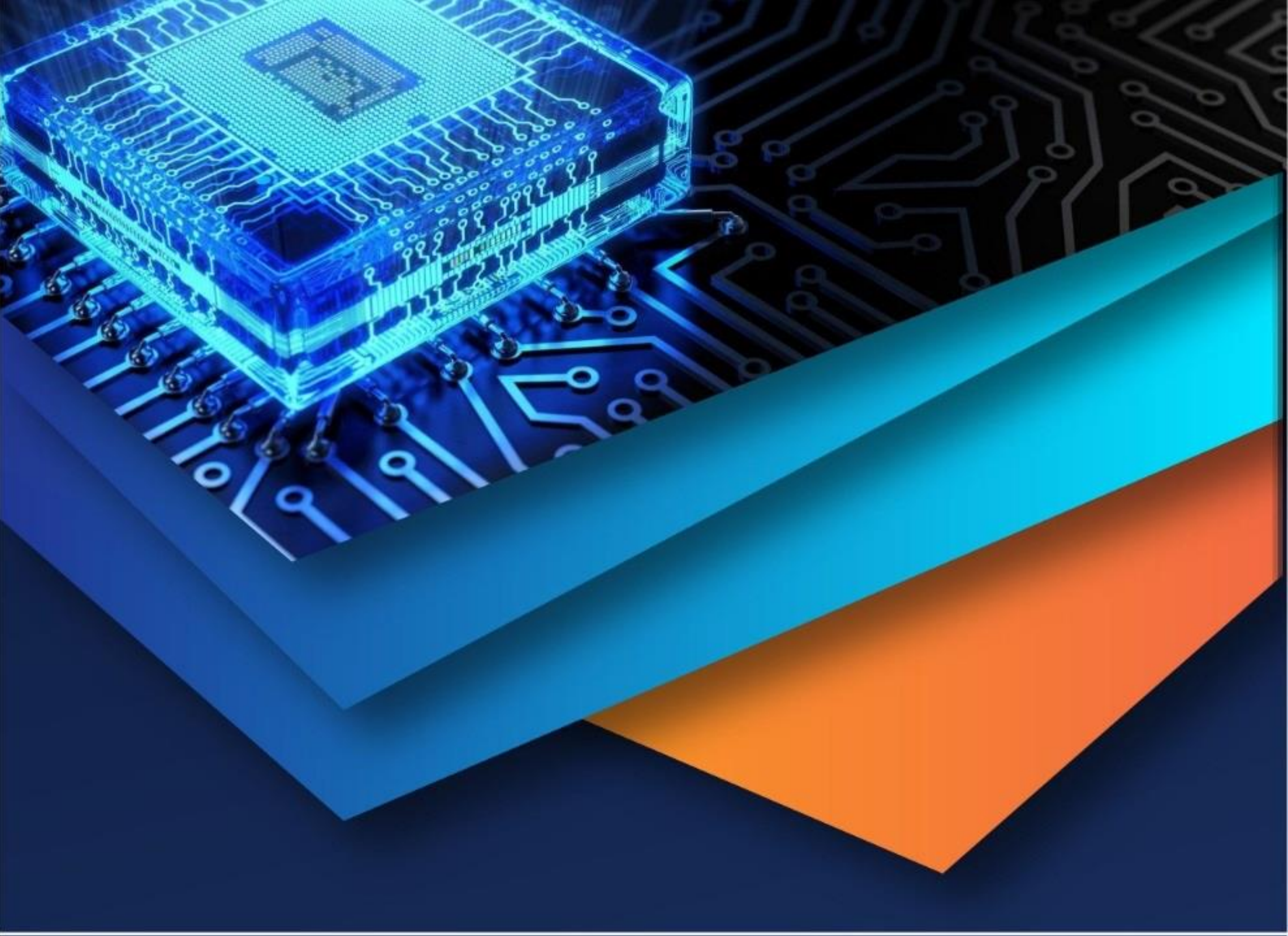

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