INVESTIGATION ON LATERALLY PERFORATED PLATE-FIN HEAT SINK

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Abstract - Over the past several decades, the development of electronic devices has led to higher performance. Therefore, an electronic cooling system is important for the electronic device. A heat sink which is a part of the electronic cooling system, is continuously studied in research field to enhance the heat transfer. Many researchers have studied heat transfer enhancement of plate-fin heat sink by modification on fin geometry. However, there have been only a few articles which reported the thermal performance of plate-fin heat sink with perforation. This research aims to study on the flow and heat transfer characteristics of solid-fin heat sink (SFHS) and laterally perforated plate-fin heat sink (LAP-PFHS). The SFHS and LAP-PFHSs are investigated on the same fin dimensions. The LAP-PFHSs are performed with a 27 perforation number and two different diameters of circular perforation (3 mm and 5 mm). The experimental study is conducted under various Reynolds numbers from 900 to 2,700 and the heat input of 50W. The experimental results show that the LAP-PFHS with perforation diameter of 5 mm gives the minimum thermal resistance about 25% lower than SFHS. The thermal performance factor which take into account of the ratio of the Nusselt number and ratio of friction factor is used to find the suitable design parameters. The experimental results show that the LAP-PFHS with the perforation diameter of 3 mm provides the thermal performance of 15% greater than SFHS. In addition, the simulation study is presented to investigate the effect of the air flow behavior inside the perforation on the thermal performance of LAP-PFHS.

Keywords - Heat sink, Parallel flow, Circular perforation, Non-bypass flow.

I. INTRODUCTION

Heat sink is a simple heat exchanger and widely used as a cooling system in electronic devices due to low maintenance and low cost. In past decades, there are some researchers explored improving the thermal performance of the plain fin heat [1-3]. Moreover, there are some researchers proposed the modification on fin geometry for the heat transfer improvement of plate-fin heat sink. Ismail et al. [4] numerically studied the heat transfer of plate-fin heat sink with different perforation shapes. The perforation shapes were presented with circular, square, hexagonal and triangular profiles. The thermal performance of heat sinks was investigated based on bypass flow on fin tip and turbulent flow regime. The comparison results shown that the plate-fin heat sink with hexagonal perforations provided the fin effectiveness higher than other shapes of perforation. Shaeri and Bonner [5] experimentally investigated the thermal performance of laterally perforated plate-fin heat sinks with rectangular perforation. The air flow was assumed as laminar flow and non-bypass flow. The rectangular perforation was carried out with three different perforation sizes which were based on five porosities. The performance indicator was the mass-based thermal resistance which was calculated by multiplication between thermal resistance and mass of heat sink. The experimental results showed that laterally perforated plate-fin heat sinks with the maximum porosity provided the mass-based thermal resistance lower than the solid fin heat sink of 45%.

As mentioned above, there are some researchers studied on the thermal performance improvement of heat sink with perforation on plate fin. However, there is still room for the study on the thermal performance of perforated plate-fin heat sink based on turbulent flow and non-bypass flow. The aim of this paper is to investigate the thermal performance of laterally perforated plate-fin heat sinks (LAP-PFHSs) with circular perforation. Moreover, the effect of perforation diameter are proposed.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

A schematic diagram of the experimental apparatus is presented in Fig. 1. It consists of a wind tunnel, test section and experimental measurement devices.

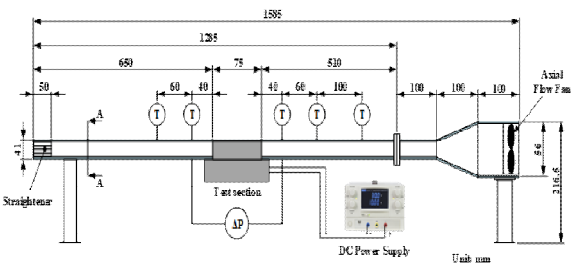


Fig. 1. Schematic diagram of the experimental apparatus.

An axial fan is installed to drive the air flowing through inside the wind tunnel. It is controlled by a DC

power supply. The experimental conditions for air velocity is conducted at ranges of 3-8 $m \cdot s^{-1}$. For the test section, the tested heat sinks are made from aluminum 6063 with a dimension of fin thickness 1 mm, channel width 3 mm, fin height 25 mm, base width 50 mm and base length 75 mm, as shown in Fig. 2. At the bottom surface of tested heat sinks, the 150-watt plate heater and bakelite plate of 40 mm thickness is connected. The differential pressure transducer is used to measure the pressure drop of tested heat sinks, which provides an accuracy of ±0.5% of full scale. The temperature is measured by the type T thermocouples which gives an accuracy of ±0.2 ^{o}C. The dimensions of the SFHS and LAP-PFHS are shown in Table 1.

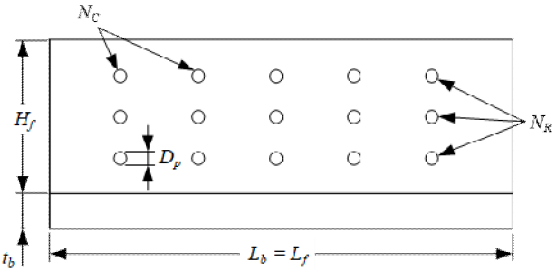


Fig. 2. The schematic view of laterally perforated plate-fin heat sink with circular perforations.

Table I Dimensions of solid fin and laterally perforated plate-fin heat sink. Unit: mm.

Base		Fin		Perforation	
Height of base, H_b	8	Length of fin, L_f	75	Number of perforation column, N_C	9
Width of base, W_b	50	Height of fin, H_f	25	Number of perforation row, N_R	3
Length of base, L_b	75	Thickness of fin, t_f	1	Diameter of perforation, D_p	3, 5

The heat transfer rate from the solid fin heat sink to the air can be calculated as follows:

$$Q_a = \dot{m}_a c_{p,a} (T_{a,avg,out} - T_{a,avg,in}) \quad (1)$$

where $\dot{m}_a$ is the mass flow rate of air, $c_{p,a}$ is the specific heat of air, $T_{a,avg,in}$ and $T_{a,avg,out}$ is average air inlet and outlet temperatures, respectively. In term of the heat supply (Q_{heater}), it is calculated by multiplying the voltage and current. The average heat transfer rate can be calculated as follows

$$Q_{avg} = (Q_a + Q_{heater})/2 \quad (2)$$

The thermal resistance (R_{th}) of the solid fin heat sink can be calculated by

$$R_{th} = \frac{(T_{b,avg} - T_{a,avg})}{Q_{avg}} \quad (3)$$

where $T_{b,avg}$ demonstrates the average temperature at heat sink base, and $T_{a,avg}$ presents the average air temperature. The Reynolds number (Re) based on hydraulic diameter can be determined by

$$\mathrm{Re} = \frac{\rho V_{ch} D_h}{\mu} \quad (4)$$

where V_{ch} is the velocity of the air in a channel, and D_h is the hydraulic diameter of the channel. The hydraulic diameter of the channel can be calculated as follows:

$$D_h = \frac{4A_{ch}}{P_{ch}} \quad (5)$$

where A_{ch} is the cross-sectional area of the flow channel and P_{ch} is the wetted perimeter of the channel. The heat transfer coefficient and Nusselt number are calculated as follows, respectively

$$h = \frac{Q_a}{\eta A_{conv} (T_{base,avg} - T_{a,avg})} \quad (6)$$

$$Nu = \frac{hD_{ch}}{k} \quad (7)$$

where η is fin efficiency, A_{conv} is the total of convective heat transfer area. $T_{base,avg}$and $T_{a,avg}$ represent the average temperatures of the base and air, respectively.

The friction factor in the flow passage of plate-fin heat sink is calculated by

$$f = \frac{2\Delta P D_{ch}}{\rho V_{ch}^2 L_{ch}} \quad (8)$$

The thermal performance factor (η) which is used as the indicator parameter can be calculated from

$$\eta = \frac{(Nu/Nu_s)}{(f/f_s)} \quad (9)$$

where Nu_s and f_s is Nusselt number and friction factor of solid fin heat sink.Submit your manuscript electronically for review.

III. RESULTS AND DISCUSSION

The LAP-PFHS is conducted with 2 different perforation diameters under a given fin area of 1875 mm^2 (75×25 mm). The Fig. 3 shows the pressure drop of SFHS and LAP-PFHSs with various Reynolds numbers. It is evident that thermal resistance decreases when the cross-cut length increases from 0.5 mm to 1.5 mm. At the same Re, it is clearly seen that the total pressure drop of LAP-PFHS increases when the perforation diameter increases from 3 mm to 5 mm. Although the frictional pressure drop is decreased, the total pressure drop continuously increases. The reason for this is that the effect of pressure drag on total pressure drop is dominant as discussed by Gatski and Grosch [6]. Moreover, it can be observed that the

effect of perforation on total pressure drop of LAP-PFHS with D_p = 3 mm is obtained at Re > 2000. As shown in Fig. 4, the thermal resistance of SFHS and LAP-PFHSs are investigated with different Reynolds numbers. It is evident that thermal resistance of LAP-PFHS is lower than that of SFHS for all conditions.

This is because the effect of turbulent flow is higher than that of the reduction of heat transfer area due to perforation. The experimental results show that the LAP-PFHS with perforation diameter of 5 mm gives the minimum thermal resistance about 25% lower than SFHS. However, it is slightly changed when the perforation diameter is changed between 3 mm and 5 mm.

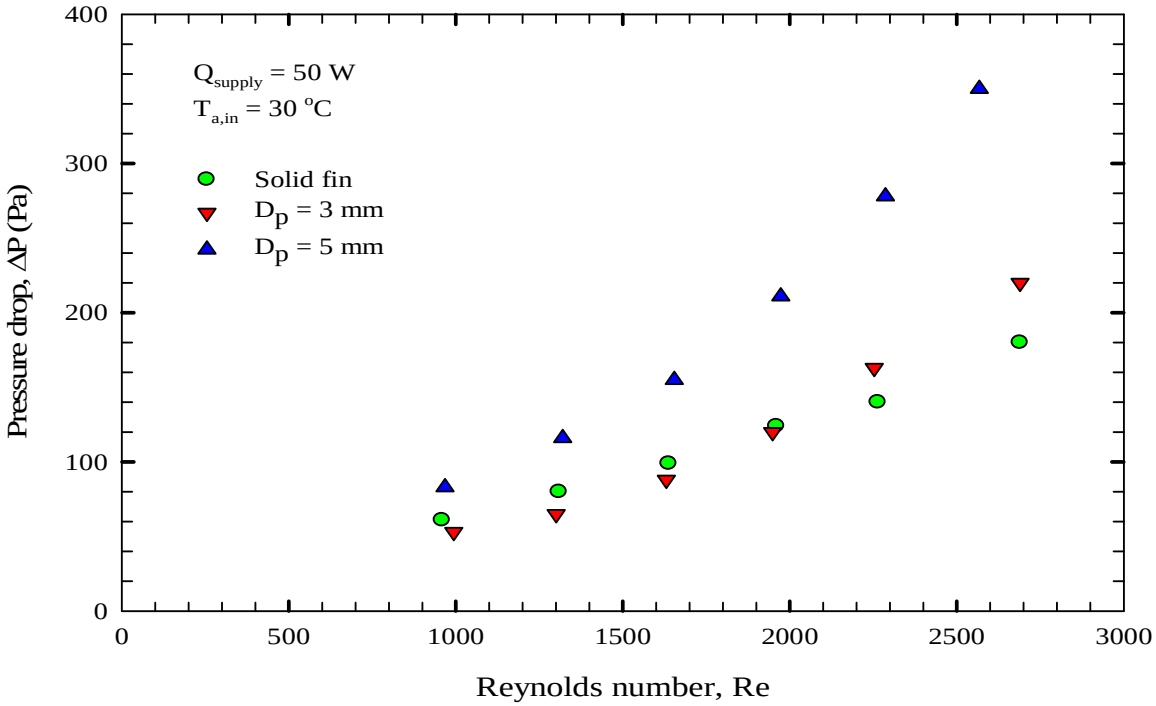


Fig. 3. The effect of perforation diameters on pressure drop.

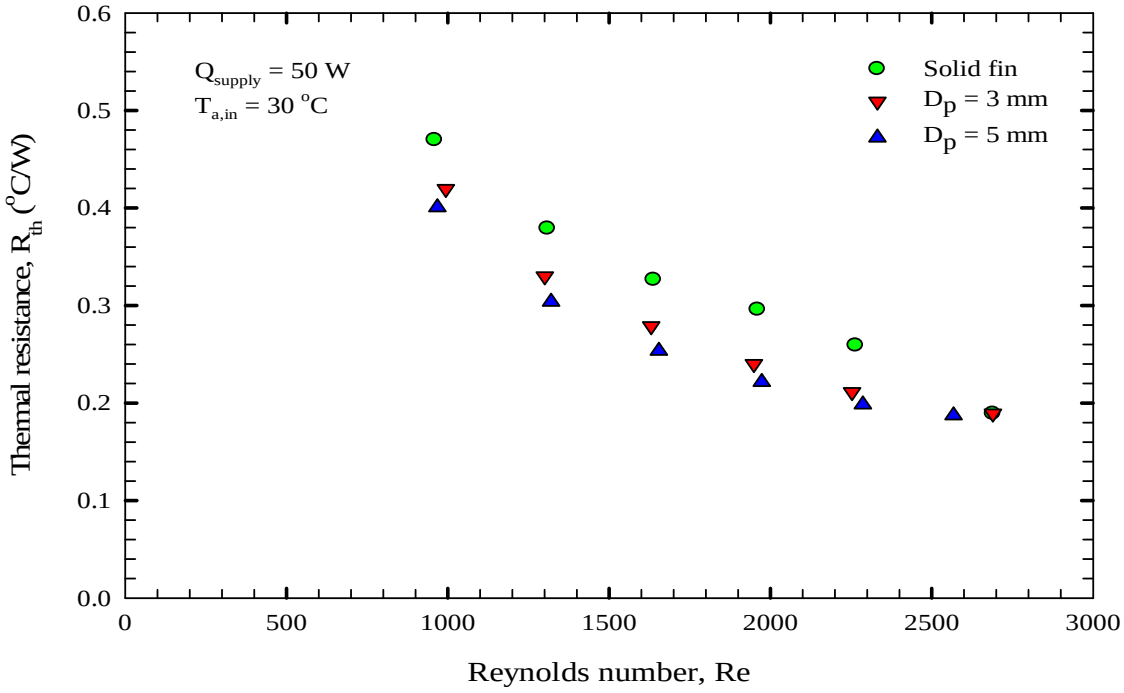


Fig. 4. The effect of perforation diameters on thermal resistance.

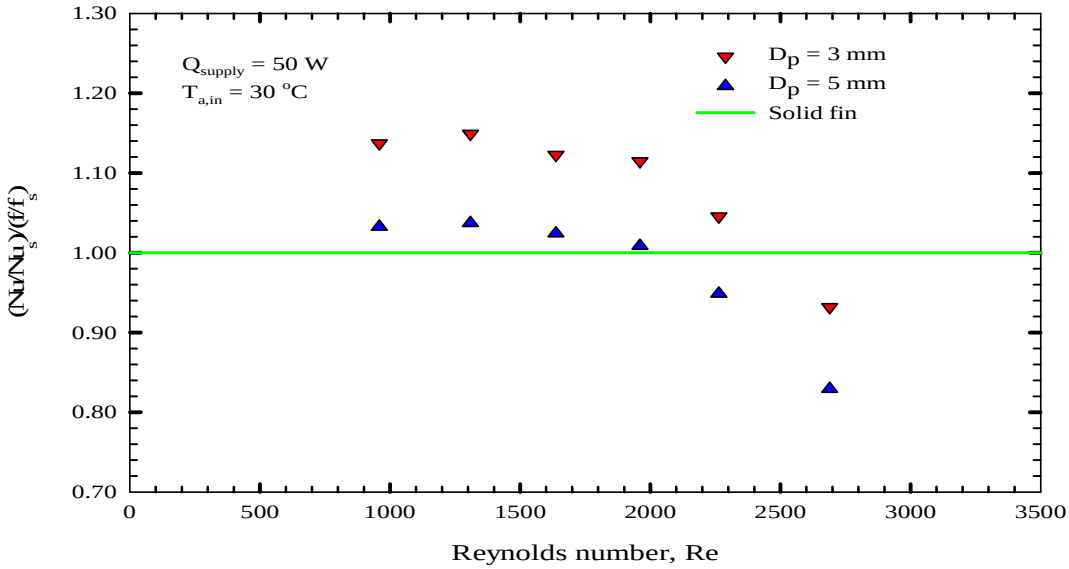


Fig. 5. The thermal performance factor of perforated plate-fin heat sink.

In order to obtain the optimal LAP-PFHS, the thermal performance factor (η) is presented as shown in Fig. 5. It can be observed that the thermal performance of LAP-PFHS decreases when the Reynolds number increases. This is the fact that the total pressure drop is the dominant effect in the thermal performance. At Re = 1300, the optimal diameter of circular perforation is achieved at D_p = 3 mm. The optimized LAP-PFHS gives about 15% the thermal performance higher than SFHS. Moreover, it can reduce the volume of heat sink material to 10% when compared to SFHS.

CONCLUSIONS

This paper aims to study the thermal performance of solid fin and laterally perforated plate-fin heat sinks. The effects of perforation diameter (D_p) on pressure drop, thermal resistance and thermal performance are presented. The lowest thermal resistance is obtained at D_p = 5 mm. Meanwhile, the laterally perforated plate-fin heat sinks with D_p = 5 mm provided the maximum pressure drop for all experimental conditions. In addition, the thermal performance factor is considered to find the optimum LAP-PFHS. From the experimental results, it can be concluded that the plate-fin heat sink with circular perforation give the thermal performance better than the solid fin heat sink. The best performance of LAP-PFHS is obtained at D_p = 3.

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