Optimal height ratio of Y-shape pin fin to plate fin of PPFHS

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Abstract. The purpose of this study is to determine the optimal ratio of Y-shape pin fin height to plate fin height in order to maximize the cooling performance of the plate pin fin heat sinks. The three-dimensional model of plate pin fin heat sink is considered in this study. Computational fluid dynamic method is used as a tool for solving the model. In this study, four values of height ratio, 0.2, 0.4, 0.6 and 0.8, and five values of air velocity, 0.5, 1.0, 1.5, 2.0 and 2.5 m/s, are analysed. The results of the study showed that the optimal fin height ratio is 0.6 resulting in the lowest thermal resistance of the plate pin fin heat sink.

Keywords: Computational fluid dynamics, plate pin fin heat sink, Y-shape pin fin

1. Introduction
One of the most significant problems associated with heat inside a computer is occurs while the computer is working. For example, more heat is caused inside the computer due to the increase in temperature if the central processing unit (CPU) of a computer is working with high data processing. A heat sink is a piece of equipment that reduces the operating temperature of computers and electronics devices. The heat sink is designed to increase the surface area linked with the thermal convection and radiation from the heat sink to the surrounding environment, such as the air. A heat sink is essential for releasing heat because it can prevent damage or unusual work by other components in the computer when in use. Various designs for the heat sink have been developed, including plate fin heat sink, pin fin heat sink and plate pin fin heat sink resulting from the combination of the plate fin heat sink and pin fin heat sink. The plate pin fin heat sink can improve the efficiency of cooling better than plate fin and pin fin heat sinks. Mostly, heat sinks are made from highly conductive materials such as aluminium or copper. A heat sink can be connected to other components in the computer, such as a display card or central processing unit (CPU). The solder material is bonded between the heat sink and components. In addition, a fan or pump can be installed to enhance the rate of convection heat transfer from the heat sink to surrounding air. A plate pin fin heat sink (PPFHS) has seen less development. Many studies are related to the application of splitter plates to modify the hydro-thermal behaviour of plate pin fin heat sinks and the heat flow characteristics of compact plate-pin fin heat sinks [1-2]. The development of the plate fin heat sink and pin fin heat sink can be found in [3-8]. There are also studies associated with the creation of tools for testing heat transfer [9-10]. Applying computational fluid dynamics to determine heat transfer performance and optimal estimation can be found in [11-13]. Thus, the heat transfer behaviour of Y-shape pin fin heat sink resulting from the influence of air velocity and the height of pin is investigated in this study. It is expected that the results of the study will be used to make decisions concerning types of heat sinks.
2. The analytical model
The 3-D physical model of plate pin fin heat sink (PPFHS) in the present study is shown in Figure 1. The bases width is 50 mm (D) and length is 55 mm (L). The height of the base plate pin fin heat sink is 3 mm. The height of plate fin heat sink (A) is 50 mm and the distance between pin fin heat sink is 5 mm. The plate pin heat sink thickness and length are 1 mm and 4 mm, respectively. Air enters the heat sink through an inlet of win. The Y-shape pin fins heat sink thickness is 2 mm and the angle between two wings Y-shape pin fin heat sink is 6 degrees. The height of the pin fin heat sink (H) is measured from the base to the position changed to Y-shape. The fluid domain width, height and length are 50 mm, 53 mm and 105 mm, respectively. The surface around the plate pin fin heat sink surface is symmetric and the width of all wins is uniform.

3. Assumptions and properties
In this study, heat distribution throughout the base area and the velocity of air flow passing through the inlet are uniform. The air flow is assumed to be steady and turbulent due to obstruction of the Y-shape pin fin. Radiation heat transfer from the heat sink is not considered. The temperature of air is 25°C. The heat sink surfaces used in this study is made from 6061 aluminium alloy ASTM B 221 which is manufactured for extruding, welding, or wrapping a thin metal sheet on surface. The thermal properties of air and the aluminium heat sink are shown in Table 1.
**Table 1.** Air and Aluminium properties.

| Properties         | Values                      |
|--------------------|-----------------------------|
|                    | Density ($\rho$) (kg/m$^3$) | Thermal conductivity ($k$) (W/m·K) | Specific heat ($c_p$) (J/kg·K) | Viscosity (kg/m·s) |
| Air$^a$            | 1.225                       | 0.0242                               | 1006.43                        | 1.789e-5           |
| Aluminium$^b$      | 2719                        | 202.4                                | 871                            | -                  |

$^a$Air properties in this study are constant and not dependent on ambient temperature.

$^b$ASM Handbook, Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials ASM Handbook Committee, p 102 DOI: 10.1361/asmhba0001060

### 4. Theory

In order to study the influence of the Y-shape pin fin heat sink on heat transfer, computational fluid dynamics is used to obtain the solution for analysis. The equations used in this study are continuity, momentum and energy equations, as shown from Equations (1) to (3):

**Continuity equations:**

$$\nabla \cdot (\rho \mathbf{u}) = 0$$

**Momentum equations:**

$$(u \cdot \nabla) \rho \mathbf{u} = -\nabla p + \mu \nabla^2 \mathbf{u},$$

**Energy equations:**

$$u \cdot \nabla T = \frac{k}{\rho c_p} \nabla^2 T,$$

where $\nabla = \left( \frac{\partial}{\partial X}, \frac{\partial}{\partial Y}, \frac{\partial}{\partial Z} \right)$, $\rho$ is the density of air, $u$ is the velocity of air, $p$ is the pressure of air, $\mu$ is the viscosity, $k$ is the thermal conductivity and $T$ is temperature. The results obtained from the analysis of the equation (1) to (3) can be used to calculate the value of the heat sink by using Equations (4) and (5) as follows:

**Thermal resistance equations:**

$$R_{HS} = \frac{\Delta T}{Q},$$

**Fan pumping power equations:**

$$P_f = \left( \frac{\Delta p}{\rho} \right) \left( \frac{dm}{dt} \right),$$

where $R_{HS}$ is thermal resistance of the heat sink, $\Delta T = T_{jc} - T_a$ is the difference of temperature across the heat sink, $T_{jc}$ is the junction temperature between the base plate and the electronic device, $T_a$ is
ambient air temperature, $\Delta p$ is pressure drop across the heat sink ($N/m^2$), $\frac{dm}{dt}$ is air flow rate per time ($kg/s$), $P_F$ is fan pumping power.

5. Computational Method
To study the influence of the Y-shape pin fin heat sink on heat transfer by using the 3-D physical model detailed in the previous section, computational fluid dynamic is used to solve for the solutions. In the present study, air flow is assumed to be forced convection. The five values of air velocity that flow through the inlet that are studied are 0.5 m/s, 1.0 m/s, 1.5 m/s, 2.0 m/s, and 2.5 m/s, respectively. The ratio H/A is set as 0.2, 0.4, 0.6, and 0.8, respectively. The temperature of ambient air is 298 K. The heat flux on the base of the plate pin fin heat sink is kept constant at 18,200 W/m$^2$, while gravitational acceleration is set at 9.81 m/s$^2$ in a negative y direction. A 3-D tetrahedral mesh type of 0.001 m is used for mesh dependency in the experiment. The geometry parameters for the Y-shape plate pin fin heat sink are shown in Table 2.

Table 2. Geometry parameters of heat sinks.

| Fin height ratio | Node  | Element  | Number of fins |
|------------------|-------|----------|----------------|
| 0.2              | 23,195| 84,561   | 45             |
| 0.4              | 24,729| 88,365   | 45             |
| 0.6              | 26,611| 93,123   | 45             |
| 0.8              | 27,980| 95,542   | 45             |

6. Results
The influence of the Y-shape plate pin fin heat sink on heat transfer performance can be measured by using the value of thermal resistance. The results of the study are obtained by changing four values of pin height at 10, 20, 30, and 40 mm, which are written in the form of ratio of pin fin height to plate fin height at 0.2, 0.4, 0.6, and 0.8, respectively. The values for pressure drop and thermal resistance of the Y-shape plate pin heat sink are shown in Figure 2.

![Figure 2](http://example.com/figure2.png)

Figure 2. (a) Effect of pressure drop on the PPFHS and (b) Thermal resistance of the PPFHS.
Figure 2(a) displays the effect of the cross-section area on pressure drop for the pin fin heat sink. It can be seen that the increase in cross-section area results in an increase in the value of pressure drop. When pressure drop is increased, it is necessary to increase the energy of the pumping power, causing noise and energy consumption. Therefore, other factors have to be considered for future applications.

The values of thermal resistance obtained from the experiments are shown in Figure 2(b). The highest value for thermal resistance can be seen at the lowest value of air velocity, while lower values of thermal resistance can be seen when the velocity of air is increased. As the ratio is increased from 0.2 to 0.4, thermal resistance values tend to decrease. They are increased as the ratio is increased from 0.6 to 0.8. Although the surface area of heat sink is large, the increase in fin height causes the obstruction of air flow associated with heat transfer performance. From the study results, it can be concluded that the optimal fin height ratio is 0.6 for all air velocity values.

7. Conclusions
In the present study, it was found that the effect of thermal resistance was reduced when the air flow velocity was increased resulting in more energy consumption to force the air. The pressure drop tends to increase when air velocity and the ratio of Y-shape pin fins height are increased. The optimal ratio for the plate pin fin heat sink is 0.6 for this study causing the lowest thermal resistance of the plate pin fin heat sink (PPFHS). It was observed that the graphs of thermal resistance and pressure drop are similar to the parabolic curve and linear.

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