Experimental Analysis of Cylindrical Staggered Pin Fin Heat Sink for Force Convective Heat Transfer Variation and its Enhancement

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Abstract

A cylindrical, staggered pin-fin heat sink with a constant heat flow is examined in this research for its heat transfer variation and improvement. Radius 10 mm is the diameter of a pin fin made of heat sink cylindrical aluminum (Aluminum-Magnesium-Silicon Alloy). Same-material base plate, with thread used to attach the fin to the base plate. The height of the pin fin was determined by conducting three experiments. Again, two trials are run on the model to determine what values of Sx and Sy are most appropriate. The final test is done on the design pin fin array with varying air flow rates in order to achieve the goal. 2D air impingement results in a greater heat transfer rate than 1D air flow impingement, according to the results of this study. As in 1D air flow impingement, 2D air impingement provides an equal heat transfer rate on the pin fin heat sink arrays..

Keywords: *Heat transfer Enhancement, force convection, staggered perforated pin fin, 1D and 2D air impingement.*

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1. Introduction

Using fins, which have an increased surface area, is a well-known method of increasing heat transmission by convection. The heat transfer rate rises as the area of contact between the object and the surface increases. In a broad variety of technical applications, fins are utilized to improve heat transmission, such as in IC engine cooling, automotive radiators, and substation transformers. The thermal characteristics of the fluid, the velocity of the fluid flow, the spacing between pin fins, the arrangement of pin fins, the height of the pin fin, and the porosity of the pin fin material all impact the heat transfer rate of a pin fin. The heat transfer properties of inline and staggered pin fin heat sinks are discussed in (Naphon et al 2007). As compared to the in-line design, the staggered arrangement of pin fins provides a better heat transfer rate. The experiments on thermal conductivity for different materials is presented in (Bahadure et al 2014) Different pin fin designs are tested for their effect on heat transmission (Sharma et al. 2013). Drop-shaped pin fins are more efficient in transferring heat than other pin fin shapes, although they are more difficult to produce. Heat transfer enhancement and the impact of different parameters on heat transfer are the subject of experiments (B. Dhumne et al., 2013)..

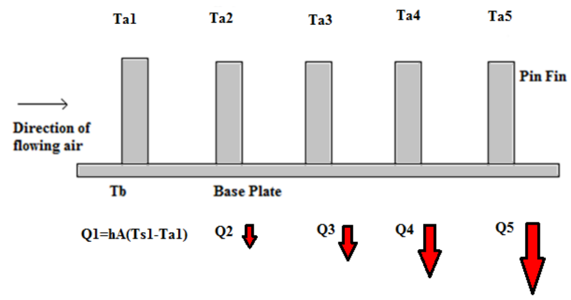

Fig. 1 Heat transfer variation on pin fin array

According to (Richard et al. 2015), CFD research shows that heat transfer rate decreases on the downstream side, and the heat transfer coefficient decreases as a result of the dusty flow pattern. (Manish Deshmukh et al 2022). For the following assertion, there is no empirical evidence to back it up. Experimentation is used in this study to back up the same claim. Pin fin array temperature and heat transfer rates are evaluated during 1D air flow impingement in this investigation. (Deshmukh Manish et al-2021). For heat transfer rate improvement, 2D air flow impingement was used in the same test portion. (Bhaskar B. S. et al. 2022). Bhaskar B. S. et al. Space heating ducts, rapid cooling of heated surfaces, etc. may benefit from this investigation.

2. Experimental set up

This research examines the steady state force convective heat transfer fluctuation in an aluminum alloy pin fin heat sink (Aluminum-Magnesium-Silicon Alloy). Fig. 2 depicts the experiment's setup. There is a test section of 250 mm, and the exit is 595 mm from the duct's entry. The channel has an interior height of 110mm and a width of 160mm. To make the temperature sensor more visible, the front of the duct is made with an acrylic material sheet, while the other sides of the duct are constructed with MS material sheet. Rubber gaskets are used to seal the joints of MS sheet duct. The speed of the two blowers, referred to as the main and secondary, may be adjusted. Primary blower is utilized for duct assembly and blows air in the 'x' direction. In order to blast air in the 'y' direction, a secondary blower is positioned perpendicularly to the main blower, which is located on the test plate portion.
Installation of the staggered pin fin array has begun. Thermal grease is used to close the space between the threads of the base plate and the fins. Install three Pencil-shaped thermocouples on the ducts' entry and exit lengths to monitor the average temperature of air entering and exiting them. Six K-type thermocouples are put on the test plate to detect temperature at different points. Below the base plate is a 1200-watt plate heater. Using thermal grease, a seal is made between the plate and heater. Six K-type thermocouples monitor the temperatures at the system's input and outflow..

Fig. 2 Experimental setup model

Five trials were undertaken to determine the best height and spacing of pin fins. Below, you will find a summary of the trial that was completed.

Table 1 Summery of trial

Sr. No.	Trial for	Height of pin fin, mm	Inter pin fin spacing in x direction, Sx mm	Inter pin fin spacing in y direction, Sy mm
1	Height of pin fin	40	12	12
2		55	12	12
3		70	12	12
4	Inter fin spacing	70	17	17
5		70	22	22

The design of test plate pin fin array is shown in fig. 3

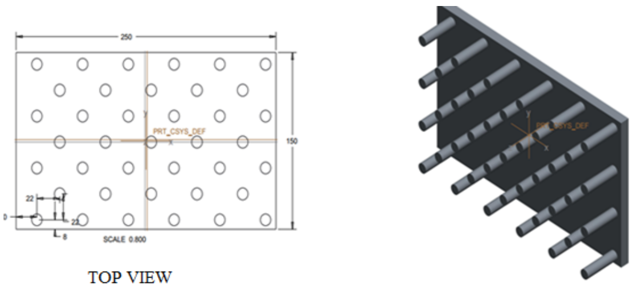

Fig 3 Design of test plate pin fin array

For the purpose of determining an appropriate pin fin height, an array of three sets of pin fin arrays was used. For example, in figs. 4 through 6, pin fin heights range from 40 millimeters to 70 millimeters, with Sx=12 millimeters and Sy=12mm. Long fins are H=55mm and H=70mm, while small fins are 40mm in height. There are three sets of pin fins to pick from in this collection.

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2.1 Pin Fin Array with H=40mm, S_x=12 mm, S_y=12mm

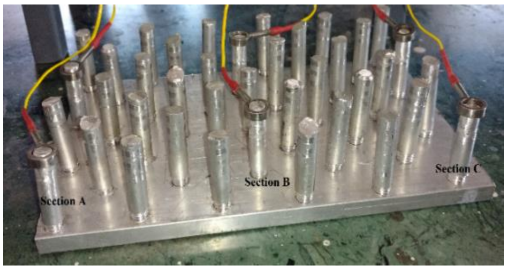

Fig. 4 Test plate with pin fin height H=40mm

The pin fin height and inter-pin fin spacing were 40 mm and 12 mm, respectively, for the first attempt. Fig. 4 depicts the first test plate. In order to determine the optimal pin fin height, this study is being undertaken.

2.2 Pin Fin Array with H=55 mm, S_x=12mm, S_y=12mm.

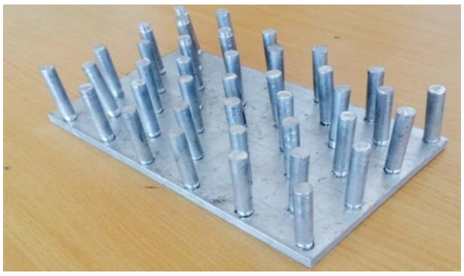

Fig. 5 Test plate with pin fin height H=55mm

A 55 mm pin fin height and a 12mm inter-pin fin spacing were used in the second attempt. The second trial's test plate is shown in Figure 5. The height of the pin fins is also measured in this experiment..

2.3 Pin Fin Array with H= 70mm, S_x & S_y=12mm

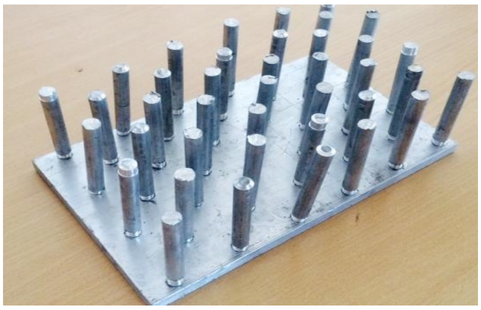

Fig. 6 Test plate with pin fin height H=70mm

70 mm pin fin height and 12mm inter pin fin spacing were used in the third attempt. In Fig. 6, we see the third trial's test plate. This testing is also carried out in order to discover the ideal pin fin height.

Calculating an appropriate inter-pin fin spacing required the use of two different pin fin arrays. Fig. 7 shows a pin fin array with Sx=17mm and Sy=17mm, whereas Fig. 8 shows a pin fin array with Sx=22mm and Sy=22mm, and it is this pin fin array that is utilized to determine the heat transfer variation calculation on a pin fin array.

2.4 Pin fin array with spacing of S_x=17mm, S_y=17mm, H=55mm

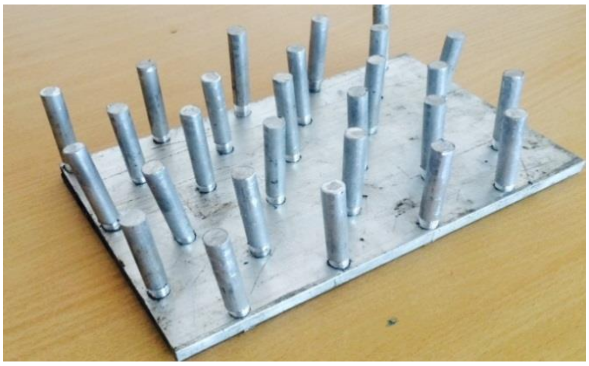

Fig. 7 Test plate with pin fin Spacing S_x=17mm, S_y=17mm, H=70mm

It took three trials to arrive at H=70mm as the final pin fin height, which is in line with the measured heat transfer rate. Pin fin spacing and height were 17 mm and 70 mm, respectively, for the fourth attempt. The purpose of this study was to determine the distance between the interpin fins.

Sx=22mm, Sy=22mm, and H=55mm in a 2.5 Pin fin array

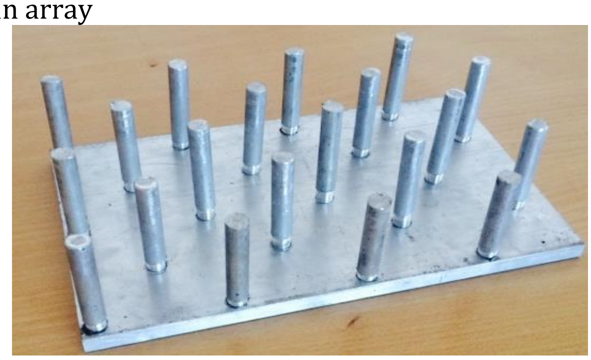

Fig. 8 Test plate with pin fin Spacing S_x=17mm, S_y=17mm, H=70mm

For fifth experiment pin fin spacing was 22mm and height 70mm. This testing was undertaken for determining inter pin fin spacing.

3. Data Reduction

Heat transmission from a heated surface may be summarized in this way: (R. Muthukumarn et al. excluded the radiation heat transfer losses).Q = h_s * A_s * (T_{out}-T_{in}) (1)

The steady state convection heat transfer rate from test can be given by

$$h_{s1} = m*C_p*\frac{(Tout-Tin)}{(T_b-\frac{Tout+Tin}{2})} \quad (2)$$

Where, m is mass flow rate of air, C_p is specific heat, Tb is base plate temperature, T_{out} and T_{in} are inlet and outlet temperature of duct. The mass flow rate were calculated by following equation

$$m=\frac{Q_a}{V_a} \quad (3)$$

Where, Q_a is discharge of orifice and V_a is volume flow rate. The Q_a value can estimated by following equation,

$$Q_a = C_d*\frac{\pi}{4}*d^2*\sqrt{2*g*\frac{h}{1000}*\frac{\rho_w}{\rho_a}} \quad (4)$$

Where, 'd' is orifice diameter, 'h' is manometric height,
ρ_w is density of manometric fluid, ρ_a is density of air flowing through duct, C_d is the coefficient of discharge of orifice.

4. Result and Discussion

Due to the direct contact of cool air on the first row of the pin fin array, heat dissipation is greater during 1D air flow.

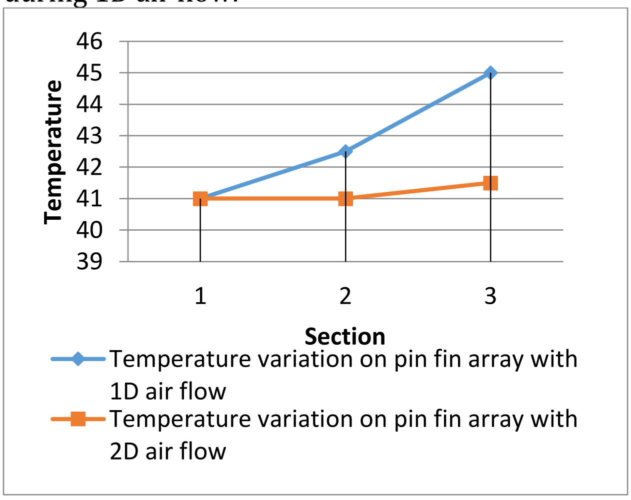

Fig. 9 Temperature in 0C Vs test plate section chart

Heat dissipation of the pin fin array diminishes in section '2' of the pin fin array, resulting in a rise in the pin fin's temperature. Because the dissipation at section '3' is so low compared to section '2', the temperature of the pin fin tip rises at section '3' as the surrounding temperature of the fin approaches the 'Tout' temperature.

Table 2 Experimentation result table

Types of Array	Type of flow	A_s (m^2)	h_s (W/m^2K)	Q (W)
S_x=12,S_y=12, H=40	1D	0.08650	72.83	**14.67**
	2D	0.08650	120.77	**20.89**
S_x=12,S_y=12, H=55	1D	0.09876	101.28	**29.40**
	2D	0.09876	130.82	**34.49**
S_x=12,S_y=12, H=70	1D	0.12326	88.69	**32.79**
	2D	0.12326	125.50	**36.04**
S_x=17,S_y=17, H=70	1D	0.1013	73.81	**22.43**
	2D	0.1013	135.52	**27.45**
S_x=22,S_y=22, H=70	1D	0.0814	99.64	**24.35**
	2D	0.0814	134.19	**32.80**

In comparison to other combinations of pin fin height and inter-pin fin spacing, the heat transfer rate for H=70mm, Sx=12mm Sy=12mm is high, as shown in the results table above..

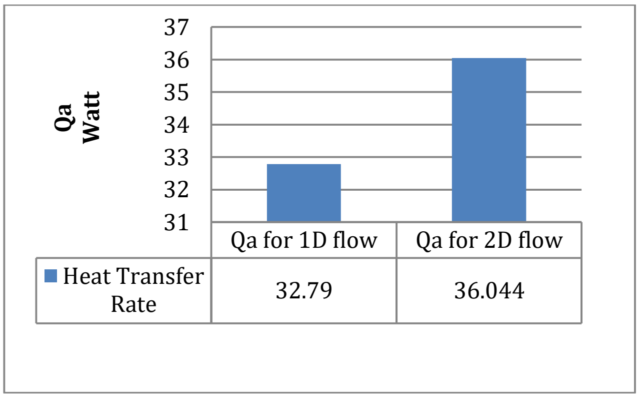

Fig. 10 Heat transfer rate in 1D and 2D air flow impingement comparison chart.

The heat transfer rate is highest when H=70mm, Sx=12mm, and Sy=12mm test plates are used in conjunction with 2D air flow impingement, as opposed to 1D air flow impingement on the same plate..

Conclusions

After performing experiment on pin fin array at constant heat flux and changing mass flow rate following points were studied.

1) When compared to 1D air flow impingement, the heat transfer rate in 2D air flow impingement is higher..
2) Pin fin heat dissipation on the downstream side continues to decrease row by row as the air temperature around the pin fins increases in 1D air flow impingement. As a result, the heat transfer rate is not uniformly distributed over the pin fins.
3) When two perpendicular air streams collide on one another, the temperature of all pin fin tips is approximately equal because to turbulence. In other words, the rate of heat transmission throughout the full surface of the pin fin array is the same..

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