Thermal performance of heat sink under natural convection: Effect of fin volume distribution

S.Y. Cheng[1,2,*], Y.S. Yeow[2]

[1]Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding author's email: cheng@utem.edu.my

ABSTRACT: The objective of the present study is to investigate the effect of heat sink volume distribution on heat transfer coefficient under natural convection. Three fin configurations which vary in heat sink volume distribution along the fin length were created under the constrain of a fixed heat sink volume to compare their cooling performance. In general, the Concave fin configuration produces the highest heat transfer coefficient (an average of 21% higher than the Flat configuration), followed by the Flat fin configuration. The Convex configuration exhibits the lowest heat transfer coefficient (an average of 26% lower than the Flat configuration). Thus, a heat sink fin should have more volume distributed at the outer region by increasing its outer edge height for better thermal performance.

Keywords: *CFD; heatsink; heat transfer*

1. INTRODUCTION

Proper cooling is essential for the operation of LED lights since about 70% of total energy input is converted to waste heat. To improve their performance, heat transfer of LED heat sink has been the subject of intense study (e.g. [1, 2, 3]). It is reported that in general the heat sink cools better with increasing fin length, fin thickness, fin height, and fin number. However, an increase in these parameters would result in higher heat sink volume or mass, thus, the material cost or manufacturing cost will also increase. To address this issue, the aim of the present study is to investigate how the distribution of the heat sink volume influence its cooling performance when subjected to natural convection.

2. METHODOLOGY

Three heat sink configurations were created to investigate how the volume distribution affect the heat transfer performance. These configurations were designated Flat, Convex, and Concave. The shape of both the Convex and Concave fins was obtained based on a sinusoidal function to ensure the total heat sink volume is held constant.

The present study solved the steady, three-dimensional, incompressible continuity and momentum equations by the SIMPLE algorithm using the commercial CFD package Ansys Fluent v16. By assuming the airflow converges towards the heat sink from all directions and then rises upwards, the symmetric boundary condition can be applied to the two vertical planes for reducing the flow to a quarter. Accordingly, the computational domain was as shown in Figure 1. The extents of the domain from the heat sink were respectively $3/4L$ and $9H$ in the horizontal and vertical directions (Figure 1) where, L is the length of the fin and H is the height of the fin. The volume of the computational domain was discretized into around 0.8 million elements using tetrahedral and prism cells.

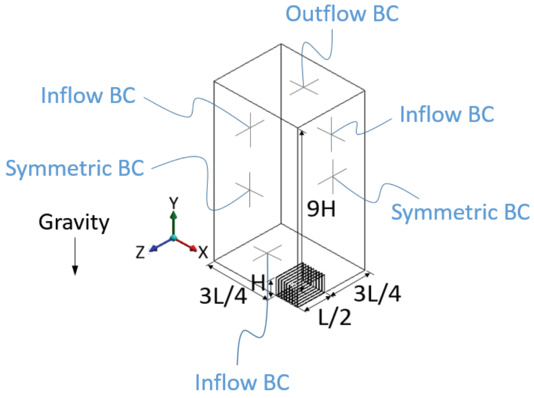

Figure 1 Computational domain and fin arrays

The viscous laminar model was used due to the Grashof number of the flow fell within the 10^3 and 10^6 range. The domain comprises three inflow boundaries and one outflow boundary (Figure 1). The base of the heat sink was assigned a constant temperature. The properties of the heat sink and air is given in Table 1.

Table 1 Test configurations of each case

	Density ρ (kg/m^3)	Specific heat C_p (j/K)	Thermal conductivity k (W/mK)	Viscosity μ (N/m^2s)	Thermal expansion α (1/K)
Air	1.204	1006.43	0.0242	1.7894x10^{-5}	0.00343
Heat sink	2719	871	202.4	-	-

3. RESULTS AND DISCUSSION

Figure 2 compares the surface temperature distribution between the Flat, Convex, and Concave configurations. In general, for all the configurations, the highest temperature occurs at the base of the heat sink. Then, the temperature progressively reduces towards the top outer corner. The comparison shows that the lowest temperature is achieved by the Concave case which has more volume distributed near the outer region (Figure 2(c)). The higher minimum temperature obtained from the Convex case as compared to the Flat case confirms that the achievable minimum temperature value is proportional to the fin volume distribution near the outer region under the constrain of fixed heatsink volume.

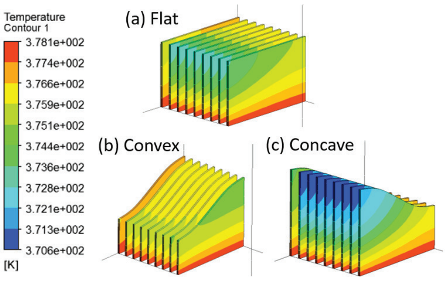

Figure 2 Heat sink surface temperature distribution

Figure 3 shows the average (over the fin surface) heat transfer coefficient as a function of temperature difference (between the base temperature and ambient air temperature). As may be expected from the result of surface temperature distribution, the Concave case exhibited the best heat transfer coefficient which is followed by the Flat case and finally the Convex case for all temperature differences tested. In term of percentage increase or decrease, the Concave case has an average (over the three temperature differences) of about 21% higher heat transfer coefficient than the Flat case, while the Convex case has an average of about 26% lower heat transfer coefficient than the Flat case.

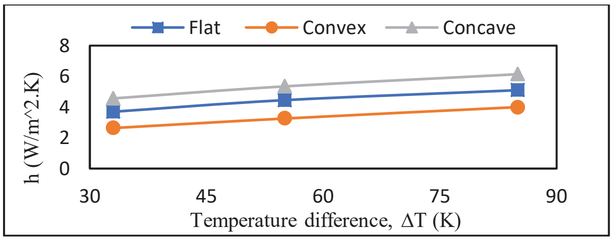

Figure 3 Average heat transfer coefficient as a function of temperature difference

Figure 4 shows the velocity vectors and air temperature distribution between two fins. Generally, the flow pattern is of a single chimney type in which the air outside of the heat sink first curves inwards towards the center of the heat sink and then rises up due to buoyancy effect. Dialameh et al. [3] has also reported the similar flow pattern which was obtained from their experimental study using a flat fin configuration.

Based on the flow patter, it is obvious that having more heat sink volume distributed at the outer region makes cooling more effective because the colder air from the outside is able to interact more with the heat sink due to larger surface area at the outer region. As the air moves towards the inner region, cooling becomes less effective partly because the air has become warmer. Another reason is that the airflow has decelerated considerably when reaching the inner region, thus, the heat transfer rate attenuates. Due to little contribution to cooling from the inner region, the Convex configuration exhibited the relatively large high temperature zone at the inner region despite the larger heat sink surface in the inner region (Figure 4(b)).

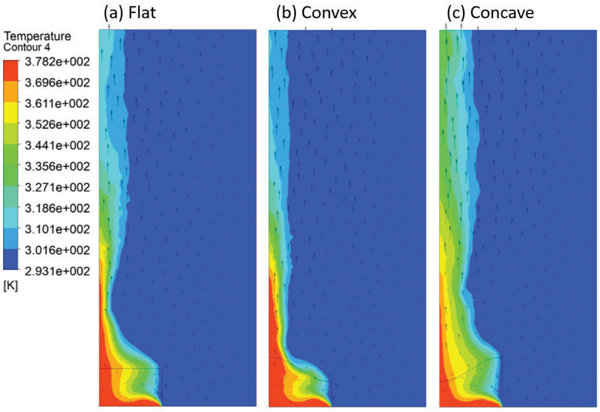

Figure 4 Air temperature velocity vector distributions in a y-z plane between the two fins next to the symmetric boundary

4. CONCLUSION

The study investigated the influence of fin configuration on the thermal performance of rectangular heat sink by a CFD method. Given a fixed heat sink volume, the fin configuration with larger heat sink volume distributed at the outer region produces higher heat transfer coefficient. Therefore, for better cooling, it is preferable to have a fin configuration with higher outer edge which resembles a concave shape.

ACKNOWLEDGEMENT

This project is supported by Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education under FRGS/2018/FKM-CARe/F00375.

REFERENCES

[1] F. Harahap and H. N. McManus, Jr., “Natural Convection Heat Transfer From Horizontal Rectangular Fin Arrays,” *Journal of Heat Transfer*, vol. 89, no. 1, pp. 32-38, 1967.

[2] K. E. Starner and H. N. McManus, Jr. 1963. “An Experiment Investigation of Free-Convection Heat Transfer From Rectangular-Fin Arrays,” *Journal of Heat Transfer*, vol. 85, no. 3, pp. 273-277, 1963.

[3] L. Dialameh, M. Yaghoubi and O. Abouali, “Natural convection from an array of horizontal rectangular thick fins with short length,” *Applied Thermal Engineering*, vol. 28, pp. 2371-2379, 2008.