# OPTIMIZATION OF HEATSINK GEOMETRY BY CFD AND CCD

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in fulfillment of the requirements for the degree
of Bachelor of Mechanical Engineering**

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**2021**

**DECLARATION**

I declare that this project entitled "Optimization of heatsink geometry by CFD and CCD" is the result of my own work except as cited in the references.

Signature : ……………………………….

Name : ……………………………….

Date : ……………………………….

**SUPERVISOR'S DECLARATION**

I have checked this report, and the report can now be submitted to JK-PSM to be delivered back to the supervisor and to the second examiner.



Signature : ………………………………...

Supervisor’s Name : ………………………………...

Date : ………………………………...

**DEDICATION**

To my beloved father and mother, thank you for your unwavering support, encouragement, and care for me

# ABSTRACT

The traditional flat plate heat sink design is still mainly used in the cooling of electronic components. The present study aims to propose a better heat sink design under a fixed mass constraint of fin distribution. The numerical results of CFD simulation for flat plate heat sink were compared with experimental results and numerical results done by previous researchers. The results showed a good agreement as the percentage difference is 3.92%, which is deemed acceptable. Three different heat sink designs, namely Flat, Convex, and Concave, are made, and their average heat transfer coefficient is compared with the Flat type heat sink being the reference model. The flow field pattern around the fins was observed, and it was found that increasing the fin mass distribution towards the side where it faces the inlet air can result in a high rate of heat transfer. Upon comparing the three designs, the Concave type heat sink has the highest average heat transfer coefficient with 26.65% better performance than the Flat type heat sink at $\Delta T = 55K$. On the other hand, Convex type heat sink has a reduction of 30.33% in average heat transfer coefficient compared to the Flat type heat sink at $\Delta T = 55K$. Finally, the best design of heat sink is predicted using the CCD method. The best design has an average heat transfer coefficient of 6.2502 $W/m^2K$ at an optimal setting of two factors: amplitude of wavelength and heat sink base thickness.

# ABSTRAK

*Penggunaan reka bentuk sinki haba plat rata tradisional bersegi empat masih digunakan secara meluas terutamanya dalam penyejukan komponen elektronik. Kajian ini bertujuan untuk mencadangkan reka bentuk sinki haba yang lebih baik di bawah had berat tetap pengedaran sirip sinki haba. Hasil simulasi numerik CFD untuk sinki plat rata bersegi empat dibandingkan dengan hasil eksperimen dan hasil simulasi numerik yang dilakukan oleh penyelidik sebelumnya. Hasil kajian menunjukkan persetujuan yang baik kerana perbezaan peratusannya adalah 3.92%, yang dianggap dapat diterima. Tiga reka bentuk sinki haba yang berbeza, iaitu Flat, Convex, dan Concave dibuat dan kadar pemindahan haba mereka dibandingkan dengan sinki haba jenis Flat menjadi model rujukan. Corak medan aliran di sekitar sirip diperhatikan, dan didapati bahawa peningkatan amplitud sirip di sisi di mana ia menghadap ke udara masuk boleh menghasilkan kadar pemindahan haba yang tinggi. Setelah membandingkan ketiga-tiga reka bentuk, sinki haba jenis Concave mempunyai kadar pemindahan haba purata tertinggi dengan prestasi 26.65% lebih baik daripada sinki haba jenis Flat pada $\Delta T = 55K$. Sebaliknya, pendingin haba jenis Convex mempunyai pengurangan 30.33% dalam kadar pemindahan haba purata berbanding sinki haba jenis Flat pada $\Delta T = 55K$. Akhirnya, reka bentuk heat sink terbaik diramalkan menggunakan kaedah CCD. Reka bentuk terbaik mempunyai kadar pemindahan haba sebanyak 6.2502 $W/m^2K$ pada tetapan optimum dua faktor: amplitud panjang gelombang dan ketebalan dasar pendingin.*

## ACKNOWLEDGEMENTS

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| | |
|---|---|
| $\dot{Q}_{cond}$ | heat transfer rate through conduction |
| $\dot{Q}_{conv}$ | heat transfer rate through convection |
| $k$ | thermal conductivity of material |
| $A$ | heat transfer area |
| $T_1$ and $T_2$ | wall face temperature |
| $\Delta x$ | wall thickness |
| $\beta$ | volume expansion coefficient |
| $\rho$ | Density |
| g | gravitational acceleration |
| Gr | grashoff number |
| $T_s$ | temperature of surface |
| $T_\infty$ | temperature of fluid sufficiently far from the surface |
| Lc | characteristic length of the geometry |
| $\nu$ | kinematics viscosity of the fluid |
| $Ra$ | rayleigh number |
| Pr | prandtl number |
| $\alpha$ | thermal diffusivity |
| $Nu$ | nusselt number |
| $u$ | velocity in x-direction |
| $v$ | velocity in y-direction |
| $w$ | velocity in z-direction |
| $\rho_f$ | density of fluid |
| $\mu_f$ | dynamic viscosity of the fluid |
| $c_p$ | coefficient of heat capacity |
| S | fin spacing |
| H | fin height |
| th | fin thickness |
| 2L | total length of the fin |

| | |
|---|---|
| $t$ | thickness of fin arrays |
| $t_b$ | heat sink base thickness |
| $L$ | length of fin |
| $n$ | number of spacing in fin arrays |
| $A$ | Amplitude of cosine wave |
| $T_a$ | ambient temperature |
| $T_b$ | Base surface temperature |
| $\Delta T$ | Temperature difference between base surface and ambient air, $(T_b - T_a)$ |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

A heat sink is a heat exchanger that transfers heat passively. Heat sinks are often constructed of metallic pieces attached to a device that releases heat energy in order to dissipate that heat to a surrounding fluid and keep the device from overheating. They are usually paired with a fan to prevent overheating of components. They are mainly used in electronic components such as CPUs, GPUs, LED, RAM, etc. Heat sinks conduct heat from electronic devices and dissipate them through convection and radiation.

Depending on heat dissipations, heat sinks can be divided into passive heat sinks, active heat sinks, and semi-active heat sinks. In passive heat sinks, the heat is dissipated through natural convection. In active heat sinks, a fan is usually paired with the heat sink and heat is dissipated through forced convection. The fan will spin non-stop when power is supplied in active heat sink. On the other hand, semi-active heat sinks work with the same principle with active heat sinks, but the fan will only spin when temperature of electronic component such as GPU is above optimal temperature. When temperature of GPU drops below optimal temperature, the fan will be idle.

Forced air convection is a more effective solution compared to natural convection (Amit Shah et al., 2006). However, it is more costly due to additional parts required and it also takes up more space. The preferences of heat sinks using natural convection and forced convection are subjective as they depend on the situation.

Computational fluid dynamics (CFD) are commonly used to study the performance of heat sink in electronic cooling. CFD is a numerical approach that uses computers to solve algebraic equations. By using CFD, thermal distribution of heat sink can be simulated to find out the heat transfer performance which then leads to optimization of heat sink to find the best heat sink design.

Central composite design (CCD) is a method that helps to reduce the number of simulations required. It uses statistical software such as Minitab to calculate optimal configurations for a design. CCD is able to generate a regression equation that relates the factors and response. From this equation, the relationship of each factor towards the response can be found. CCD can be considered as an optimization method to find out the best design.



The importance of current work is to find out the difference in heat sink performance by natural convection with different geometries under the constraint of a fixed total mass of fin material to cool heat source using computational fluid dynamic (CFD). Then, optimal heat sink geometry is to be computed using central composite design (CCD).

## 1.2 PROBLEM STATEMENT

Many experimental and numerical studies on the topic of natural convection heat transfer for flat type rectangular fin arrays have been done. Most of these studies were related to the effects of various fin geometries and temperature difference based on fin geometry on the natural convection heat transfer of heat sinks. However, the effect of fin mass distribution across the heat sink under constraints of the fixed total mass of fin material remains questionable due to limited reporting in the literature. Therefore, the present study aims to propose an efficient heat sink with a better heat transfer rate by changing the fin mass distribution across the heat sink under the constraint of a fixed total mass of fin material.

## 1.3 OBJECTIVES

The objectives of this study are as follows:

1. To study and compare the thermal distribution and performance of 3 different type of heat sink namely Flat, Convex and Concave by using CFD.
2. To compute optimal configuration of heat sink geometry and dimensions using CCD.
3. Use CFD simulation to verify the results from CCD and decide the final design.

## 1.4 SCOPE OF STUDY

The scopes of this study are:

1. The heat sink type is of rectangular base.
2. Flat type heat sink is a heat sink with even mass distributed.
3. Convex type heat sink is a heat sink with more mass distributed at the inner region.
4. Concave type heat sink is a heat sink with more mass distributed at the outer region.
5. The range of temperature difference at base of heat sink is from 33K to 85K.



## 1.5 GENERAL METHODOLOGY

The methods required to achieve the objective of the study are listed below.

1. Design drawing

   Drawing of heatsink design using Solidworks software.

2. Simulation using CFD

   Simulation of heatsink design using Ansys Fluent software to study the thermal distribution and performance of the heatsink designed.

3. Validation

   Simulation result obtained will be compared with results obtained from previous researcher.

4. Optimization using CCD.

   Calculation of optimal configuration geometry and dimension using Minitab software.

5. Analysis and evaluation.

   Results obtained from CFD and CCD will be analyzed. Optimum configuration of heat sink will be evaluated and discussed.

**CHAPTER 2**

**LITERATURE REVIEW**

## 2.1 Heat sink.

Heat sinks are available in a variety of shapes and dimensions. One of the most common shapes used is a rectangular flat plate as they are easy to be manufactured. There have been many studies on the performance of rectangular flat plate heat sink done by researchers.

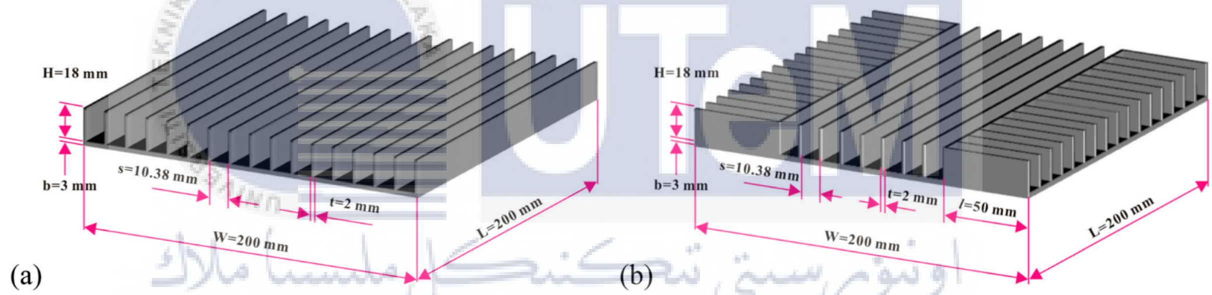



Figure 2.1: (a) Traditional rectangular flat plate heat sink (b) cross-fin heat sink

(Feng et al.,2018)

The design shown in Figure 2.1(b) can increase the overall heat transfer coefficient, which includes convection and radiation by 11% and convection heat transfer coefficient only by 15% as compared to the traditional plate-fin heat sink in Figure 2.1(a) (Feng et al., 2018).

Ledezma and Bejan (1996) studied heat sink performance by changing array configurations in their study. Figure 2.2 shows the design of the heat sink studied by them. Figure 2.3 shows the array configuration reviewed by them. The best plate fins, according to their research, are those with crests slanted such that their tips face the approaching flow.

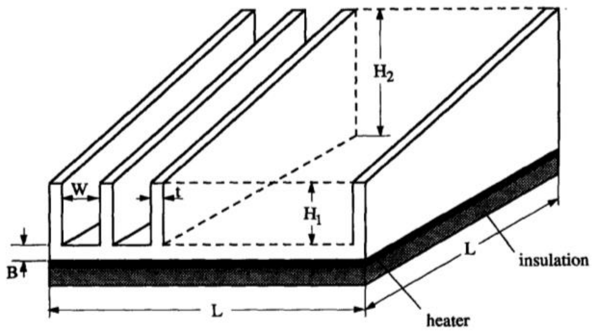



Figure 2.2: Heat sink with sloped plate fins (Ledezma and Bejan, 1996)

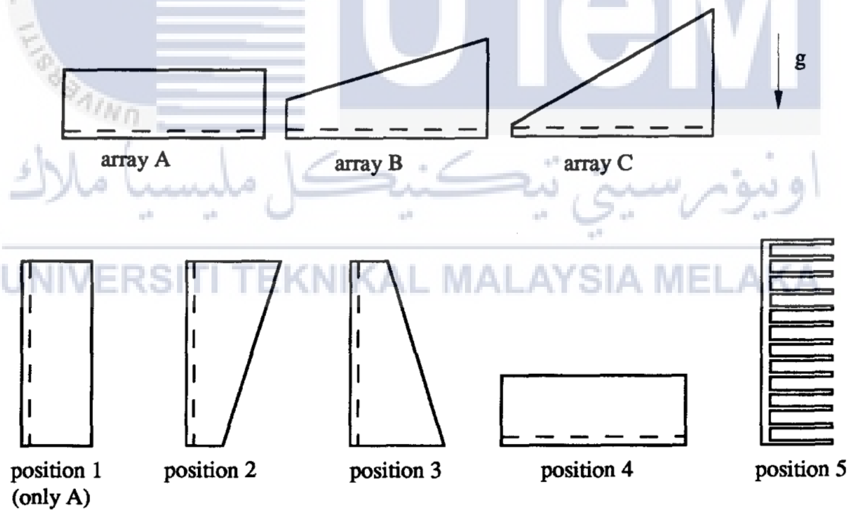



Figure 2.3: Illustration of arrays studied by Ledezma and Bejan (1996)

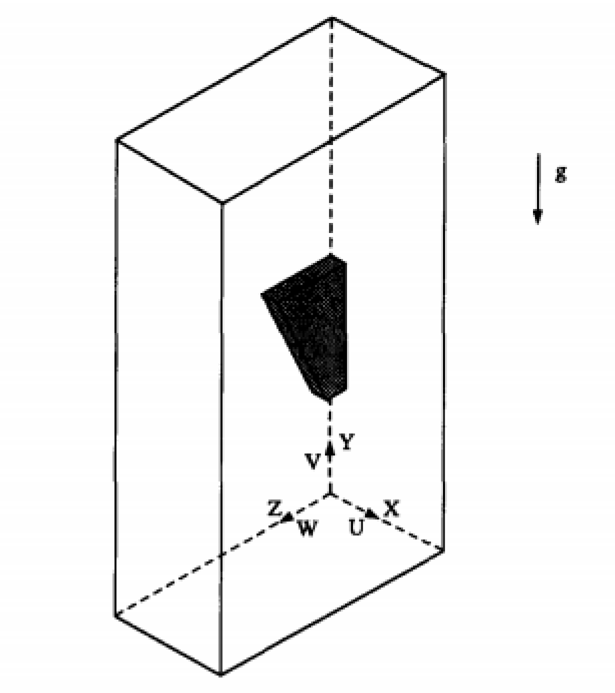
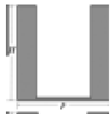
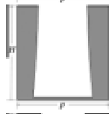
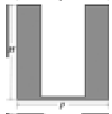
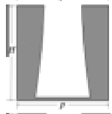
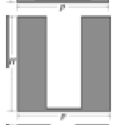
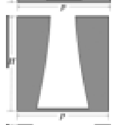
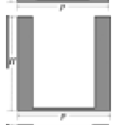
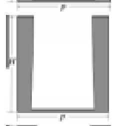
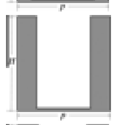
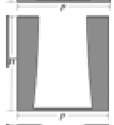
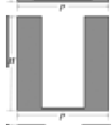
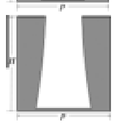



Figure 2.4: Computational domain studied by Ledezma and Bejan (1996)

Kim (2012), on the other hand, studied about the performance of heat sinks under natural convection by varying thickness of flat plate heat sinks. When the thickness of the heat dissipator was permitted to increase in a direction perpendicular to the fluid flow, he found that the thermal resistance was lowered by up to 10%. The difference between the thermal resistance of heat sinks with uniform thickness diminishes as the height and heat flux decreases (Kim, 2012). The same principle applies to heat sinks with variable thickness. Figure 2.4 shows results studied by Kim (2012).

Comparison of geometries and thermal resistances of optimized heat sinks

| Dimensionless heat flux | Dimensionless height | Type of fins | Dimensionless fin pitch | Porosity | Thermal resistance (°C/W) | Schematic of channel (not to scale) |
|---|---|---|---|---|---|---|
| $\frac{g\beta\rho_f^2 c_f q'' L^4}{\mu_f k_f^2}$ | $\frac{H}{L}$ | | $\frac{P}{L}$ | $\varepsilon$ | $R$ | |
| $5.45 \times 10^{10}$ | 1.5 | Uniform thickness | 0.0538 | 0.59 | 0.0545 |  |
| | | Variable thickness | 0.0533 | $0.655 - 0.192Y + 0.0770Y^2$ | 0.0538 |  |
| $5.45 \times 10^{11}$ | 1.5 | Uniform thickness | 0.0433 | 0.488 | 0.0334 |  |
| | | Variable thickness | 0.0403 | $0.604 - 0.321Y + 0.130Y^2$ | 0.0320 |  |
| $5.45 \times 10^{12}$ | 1.5 | Uniform thickness | 0.0358 | 0.385 | 0.0221 |  |
| | | Variable thickness | 0.0282 | $0.577 - 0.479Y + 0.178Y^2$ | 0.0197 |  |
| $5.45 \times 10^{10}$ | 1.0 | Uniform thickness | 0.0454 | 0.674 | 0.0592 |  |
| | | Variable thickness | 0.0454 | $0.702 - 0.0866Y + 0.0315Y^2$ | 0.0591 |  |
| $5.45 \times 10^{11}$ | 1.0 | Uniform thickness | 0.0347 | 0.581 | 0.0342 |  |
| | | Variable thickness | 0.0344 | $0.649 - 0.207Y + 0.0836Y^2$ | 0.0336 |  |
| $5.45 \times 10^{12}$ | 1.0 | Uniform thickness | 0.0282 | 0.475 | 0.0211 |  |
| | | Variable thickness | 0.0258 | $0.600 - 0.339Y + 0.136Y^2$ | 0.0201 |  |

$W = L = 40$ cm, $\mu_f = 0.00002$ kg/m s, $c_f = 1008$ J/kg K, $\rho_f = 1.06$ kg/m3, $k_f = 0.028$ W/m K, $k_s = 175$ W/m K, $g\beta = 0.0295$ m/s$^2$ K.

Figure 2.5: Comparison of geometries and thermal resistances of optimized heat sinks (Kim,2012)

Harahap & McManus (1967) studied natural convection heat transfer of horizontal rectangular fin arrays.

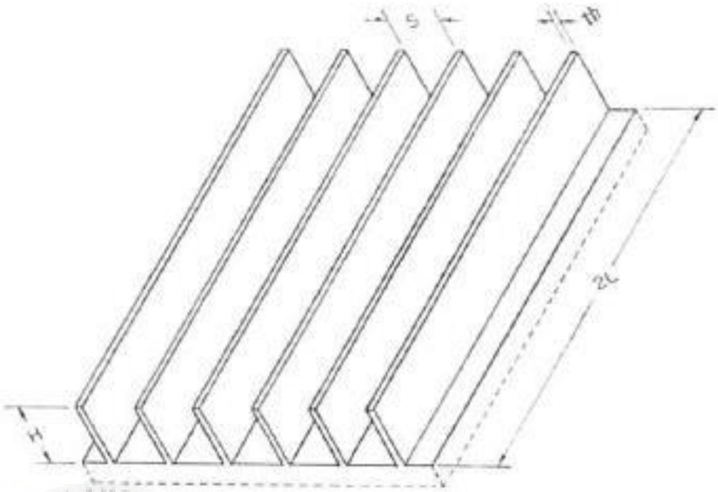


Figure 2.6: Fin array configuration studied by Harahap & McManus (1967)

The single chimney flow pattern had better heat transfer performance compared to a sliding chimney flow pattern from their study. They recommended that sliding chimney flow patterns should be avoided.



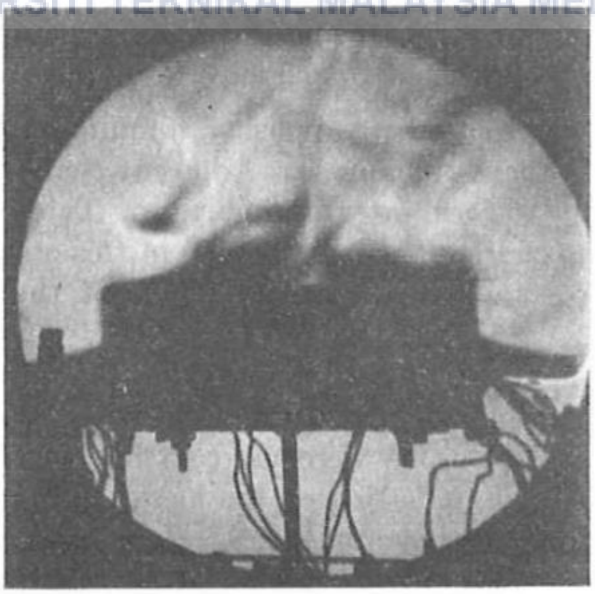


Figure 2.7: Illustration of single chimney flow (Harahap & McManus, 1967)