# CFD MODELLING OF LED HEAT SINK: GEOMETRIC OPTIMIZATION

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# CFD MODELLING OF LED HEAT SINK: GEOMETRIC OPTIMIZATION

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in fulfillment of the requirements for the degree of
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**DECLARATION**

I hereby declare this project report entitled "CFD Modelling of LED Heat Sink: Geometric Optimization" is the result of my own research except as cited in the references.

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| Name | : | ………………………… |
| Date | : | ………………………… |

## APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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| Signature | : ………………………. |
| Supervisor's Name | : ………………………. |
| Date | : ………………………. |

**ABSTRACT**

Natural convection heat transfers around a horizontal rectangular heat sink still provide too much of significance in dissipating the waste heat generated by Light Emitting Diode (LED) into the air. The present study aims to propose an efficient heat sink without increasing production cost to obtain better heat transfer rate by natural heat transfer convection without excessive usage of material. An approach that is changing the fin mass distribution across the heat sink under the constraint of a fixed total mass of fin materials has been studied. The numerical results were compared with experimental results and it showed a good agreement. To select the optimal configuration of fins, three different types of heat sink (Flat, Convex, and Concave models) were compared. The flow field pattern around the fins was observed and it can be concluded that decreasing the fin height from the outer side to the inner side of the heat sink can produce a high rate of heat transfer. By comparing the average heat transfer coefficient of the three models, the Concave model is selected as the optimal configuration of fins. This is because the Concave model has more than 20% improvement in the average heat transfer coefficient as compared to the Flat model. Whilst, Convex model has more than 20% reduction in average heat transfer coefficient as compared to the Flat model. Finally, the optimization for the average heat transfer coefficient considering various fin height and heat sink base thickness was performed. It was able to produce a maximum average heat transfer coefficient of 10.4136 $W/m^2K$ at optimal settings of fin height and heat sink base thickness.

# ABSTRAK

*Pemindahan haba perolakan semula jadi di sekeliling sinki haba yang bersegi empat tepat mendatar masih memberikan impak yang besar dalam pelepasan sisa haba yang dihasilkan oleh Pencahayaan Diod Pemancar Cahaya (LED) ke udara. Tujuan penyelidikan ini adalah untuk mencadangkan sinki haba yang cekap tanpa meningkatkan kos pengeluaran supaya mendapatkan kadar pemindahan haba yang lebih baik dengan perolakan pemindahan haba semula jadi tanpa menggunakan bahan berlebihan. Pendekatan yang mengubah pengedaran jisim sirip sepanjang sinki haba di bawah kekangan jumlah jisim bahan sirip yang tetap telah dikaji. Keputusan simulasi dibandingkan dengan keputusan eksperimen dan ia menunjukkan persetujuan yang baik. Untuk memilih konfigurasi sirip yang optimum, tiga jenis sinki haba (model Flat, Convex, dan Concave) telah dibandingkan. Corak medan aliran di sekitar sirip diperhatikan dan ia dapat disimpulkan bahawa penurunan ketinggian sirip dari kawasan luar ke kawasan dalam sinki haba (jenis Concave) dapat menghasilkan kadar pemindahan haba yang tinggi. Dengan membandingkan purata pekali pemindahan haba ketiga-tiga model tersebut, model Concave dipilih sebagai konfigurasi sirip yang optimum. Hal ini kerana model Concave mempunyai lebih dari pada 20% peningkatan dalam purata pekali pemindahan haba apabila membanding dengan model Flat. Manakala, model Convex pula mempunyai lebih daripada 20% pengurangan dalam purata pekali pemindahan haba apabila membanding dengan model Flat. Akhirnya, pengoptimuman purata pekali pemindahan haba dengan mempertimbangkan pelbagai ketinggian sirip dan ketebalan dasar sinki haba telah dijalankan. Ia dapat menghasilkan purata pekali pemindahan haba yang maksimum, iaitu 10.4136* $W/m^2K$ *dalam tetapan ketinggian sirip dan ketebalan dasar sinki haba yang optimum.*

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## LIST OF SYMBOLS

| | | |
|---|---|---|
| S | = | Fin spacing |
| H | = | Fin height |
| th | = | fin thickness |
| 2L | = | total length of the fin |
| t | = | thickness of fin arrays |
| L | = | Length of fin |
| n | = | Number of spacing in fin arrays |
| $t_b$ | = | Heat sink base thickness |
| $\lambda$ | = | Thermal conductivity |
| $\alpha$ | = | Thermal expansion |
| h | = | Convective heat transfer coefficient |
| $\rho_e$ | = | Electrical resistivity |
| E | = | Modulus of elasticity |
| $\rho$ | = | Density |
| C | = | Cost |
| Q | = | Total heat transfer rate from fin arrays to the surrounding |
| A | = | Total heat transfer area of the fin arrays |
| $\Delta T$ | = | Temperature difference between the base surface and ambient air, $(T_b - T_a)$ |
| $T_b$ | = | Base surface temperature |
| $T_a$ | = | Ambient temperature |
| u | = | x-component of velocity (m/s) |
| v | = | y-component of velocity (m/s) |

| | | |
|---|---|---|
| w | = | z-component of velocity (m/s) |
| g | = | gravity, $m/s^2$ |
| μ | = | dynamic viscosity, N/$m^2$s |
| $c_p$ | = | coefficient of heat capacity, J/(kg℃) |
| $\beta$ | = | coefficient of thermal expansion |
| $Gr_H$ | = | Grashof number with respect to fin height |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

A light-emitting diode is a semiconductor device that emits light when current flow through it. Light-Emitting Diode usually denoted by the term LED. LEDs are comprised of compound semiconductor materials, such as gallium phosphide (GaP), gallium arsenide phosphide (GaAsP), and gallium arsenide (GaAs). LED light emits energy in the form of light. Practically, it also discharges energy in the form of heat. A typical LED can produce about 70% of total energy consumed as heat and thus creating a thermal problem.

Waste heat dissipation from LED gives a major impact on the performance of LED. The temperature of LED will rise due to improper dissipating of heat by a cooling system. An inefficient heat sink can cause damage to the LED's component as the temperature increases (Li et al., 2010). Besides that, the presence of waste heat will also lead to lumen degradation. Therefore, a better design of a heat sink is needed to promote heat transfer and to dissipate the waste heat properly.

A suitable cooling solution that can simply move waste heat generated by LED into the air is called a heat sink. In other words, a heat sink can transfer the heat or thermal energy from high-temperature to a low-temperature medium like air by natural convection cooling or forced air cooling. The forced air convection is the most effective solution but it is costly due to it requires some space for the installation of blower and ductwork (Amit Shah et al., 2006). So, it is important to choose effective cooling solutions to preserve the reliability of the electronic device.

The optimization of heat sink geometry is one of the most essential solutions in enhancing the thermal performance of the heat sink. The fin shape, number of fins and orientation of the fins are some of the factors on improving the thermal performance of heat sink. Besides that, various fin mass distribution across a rectangular heatsink under a fixed mass of fin material also may overcome the problems that the heatsink could not dissipate waste heat properly, which is a low average heat transfer coefficient or low heat transfer rate. These solutions are considered a cost-effective method in improving the thermal performance of heatsink because there is no excessive usage of materials in which the mass of the heat sink is kept constant throughout the distribution of fin materials.

Many tools like CFD (Computational Fluid Dynamic) and Ansys are most commonly used for heat sink optimization. With a new optimal heat sink design, LED lighting might be able to dissipate the heat effectively.

## 1.2 PROBLEM STATEMENT

Although many effective types of heat sinks have been created to dissipate more heat in LED light, the thermal problem still exists. The main challenge is to propose an efficient heat sink with a better heat transfer rate by natural heat transfer convection. Many LEDs have to face a certain amount of waste heat because of the poor and ineffective heat sink. The shortcomings of heat sink had made LED's manufacturer investigate new potential heat sink that has a bigger surface area at transferring heat.

The flow of fresh air into the heat sink is strongly impacted by the mass distribution of fins on a heat sink. The larger mass distribution of the fin can reduce fluid flow resistance, in which allowing more cooling air to enter through a heat sink. A heat sink is designed by using high usage of materials that have more mass distribution and this property makes the heat sink more expensive. Thus, the optimization of fin mass distribution must be good enough to dissipate heat and be able to produce a heat sink without excessive usage of materials.

## 1.3 OBJECTIVE

The main objective of this research is as follow.

1. To determine the optimal configuration of fins under constraint of fixed total mass and fixed mass of fin material.
2. To study the effect of fin mass distribution across heatsink towards average heat transfer coefficient.

## 1.4 SCOPE OF THESIS

The scope of this thesis are:

1. Analysis study on heat removal by heat sink under natural convection.
2. Comparative study on the effect of different configuration of fin on dissipating heat to the environment.
3. Geometry optimization of LED heat sink by using rectangular heat sink.
4. Heat transfer through the rectangular base is keep constant.
5. Radiation heat loss at the heat sink is negligible.

## 1.5 GENERAL METHODOLOGY

In this research, an approach that needed to be employed to achieve the objectives are shown as following.

1. Literature review

   The journal, websites, book or any source related to the project will be studied.

2. Visualization

   Visualization by using Computer Fluid Dynamics (CFD) to get see fluid flow pattern in heat sink.

3. Evaluation

   The selection of optimum configuration of fin and how the configuration of fin affects the average heat transfer coefficient will be discussed.

4. Prepared summary report

   At the end of the research, a report of this research will be written.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 LED Heat Sink

Heat sink is a very important fixture in a light-emitting diode (LED) because it can remove an excessive waste of heat produce by LED as the temperature rise. The effectiveness of every component in electronic devices depends on temperature, in which higher temperatures will become harmful to the reliability of these devices (Shah et. al. 2006). Therefore, an efficient heat sink is needed to promote the heat transfer rate and prevent electronic devices from overheating. To select a good quality of heat sink, there are some factors needed to be considered which are material selection, shape of a fin, surface treatment and mass flow rate of fresh air.

### 2.1.1 Horizontal Rectangular Fin Arrays

The fin array configuration of the heat sink is shown in Figure 2.1. As observed, the heat sink is constructed by using a horizontal rectangular fin and horizontal base plate. The finned surface is widely used in a variety of engineering applications because it provides a greater heat transfer area for heat transfer.

First, the process of heat transfer is started by natural convection on a finned surface. Natural convection on a surface depends on the geometry and orientation of the surface. According to Harahap & McManus (1967), the single chimney flow pattern had better heat transfer performance as compared to a sliding chimney flow pattern. Besides that, model details of natural convection for vertical rectangular fins with constant length on the vertical base can be found from an experimental study of Welling and Woolbridge. Based on the experiment carried out by Welling & Woolbridge (1965), the fin height is greatly impacted by the fin spacing, in which there is an optimum fin height for each fin spacing.

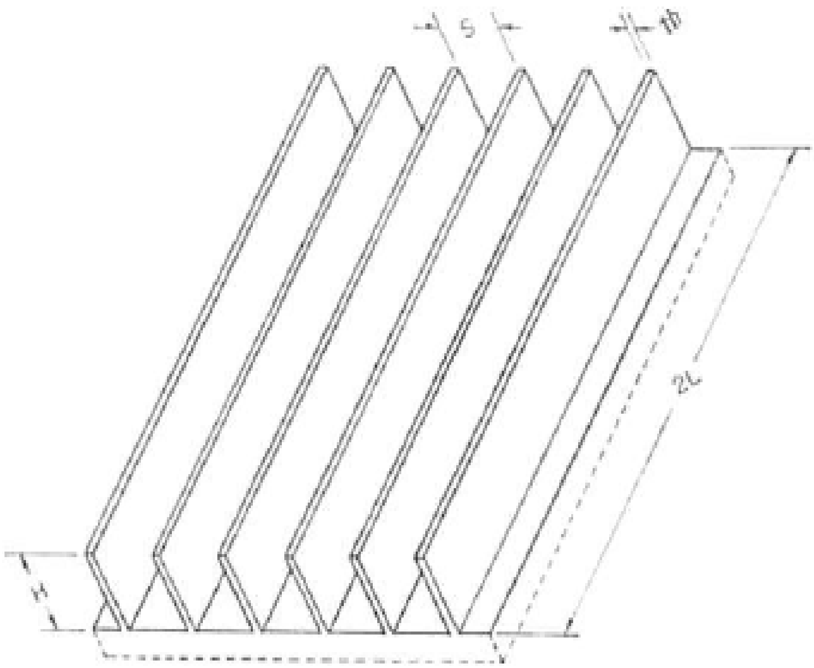

Figure 2.1: Fin array configuration (Harahap et. al, 1967)

### 2.1.2 Material of Heat Sink

For the selection of heat sink materials, thermal material with high thermal conductivity and low coefficient of thermal expansion are preferable (Ekere et. al. 2011). Based on the research studied by G. Prashant Reddy & Navneet Guptal (2010), a heat sink material with high thermal conductivity can increase the heat transfer rate. They suggested that aluminum-based alloys or metals are very optimistic materials for the heat sink. There were two case studies clearly stated by them as shown in Table 2.1.

Table 2.1: Material selection requirements (G. Prashant Reddy & Navneet Guptal, 2010).

| **Cases** | Case 1 | Case 2 |
|---|---|---|
| **Function** | Heat Sink | Heat Sink |
| **Constraints** | Material must have $p_e >$ $10^{19} \mu\Omega\ cm.$ All dimensions specified. | Temperature and volume of material decrease. High electrical resistivity. High value of Young's modulus, thermal expansion must be emphasize. |
| **Objectives** | To increase thermal conductivity | Maximize Young's modulus Heat transfer coefficient increase, temperature increase |

The graph was simulated by software based on Case 1 condition as showed in Figure 2.2. As shown in Figure 2.2, Aluminum nitrate (AIN) or Alumina $Al_2O_3$ meet the requirement for the Case 1 condition.

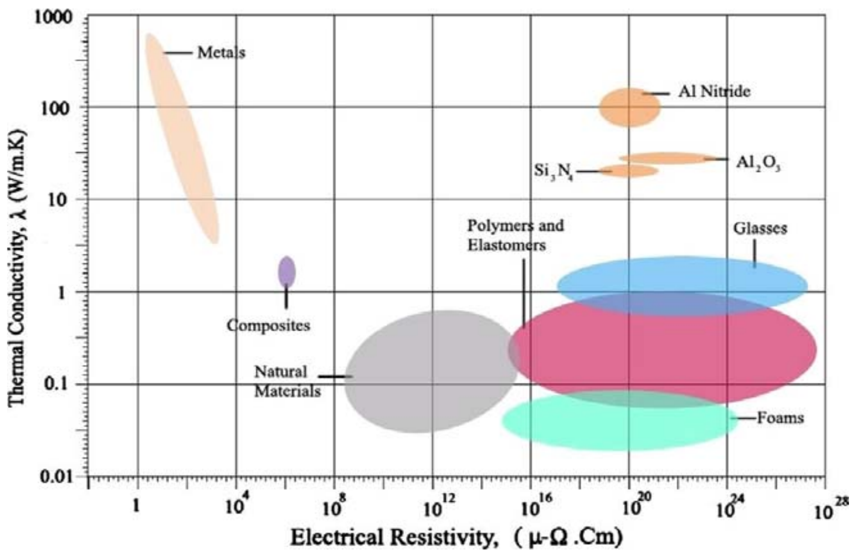


Figure 2.2: Effect of thermal conductivity toward electrical resistivity for different type of materials

(G. Prashant Reddy & Navneet Guptal, 2010)

The graph was simulated by software based on Case 2 condition as showed in Figure 2.3. As shown in Figure 2.3, Al, AIN, $Al_2O_3$ meets the requirement for the Case 2 condition.

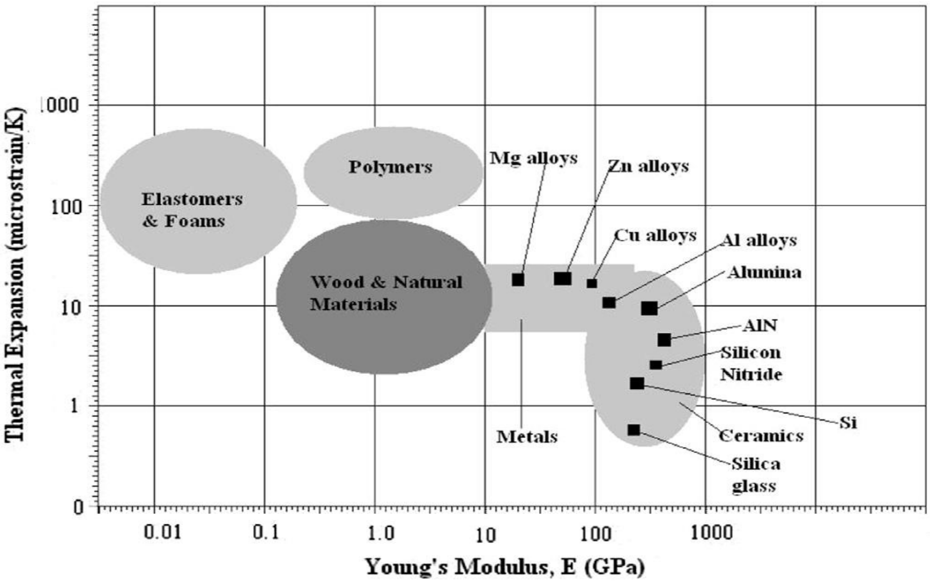


Figure 2.3: Effect of thermal expansion toward young's modulus for different type of materials (G. Prashant Reddy & Navneet Guptal, 2010)

Based on the above approach, the aluminum-based alloy is the best material to design a heat sink for the use of heat removal in microelectronic.

Furthermore, aluminum is the best choice material for producing heat sink devices (Almomani et. al. 2018). They have shown that the selection of material is based on six criteria which are thermal conductivity, thermal expansion coefficient, electrical resistance, modulus of elasticity, cost, and density. They applied a decision making technique called the Analytical Hierarchy Process (AHP) to select the best choice materials for heatsink devices.

Table 2.2: Selection criteria for heat sink material and required direction of change for each criterion (Almomani et. al. 2018).

| **Selection criterion** | **Symbol** | **Required direction of change** |
|---|---|---|
| Thermal conductivity | $\lambda$ | Maximize |
| Thermal expansion | $\alpha$ | Minimize |
| Convective heat transfer coefficient | h | Maximize |
| Electrical resistivity | $\rho_e$ | Maximize |
| Modulus of elasticity | E | Maximize |
| Density | $\rho$ | Minimize |
| Cost | C | Minimize |

Table 2.3: List of the values of the selection properties (Online Material Information Resource, 2018)

| Property | $\lambda$ | $\alpha$ | $\rho_e$ | E | $\rho$ | C |
|---|---|---|---|---|---|---|
| Material | W/m.K | $10^{-6}$/℃ | $\Omega.cm$ | GPa | g/$cm^3$ | |
| S-65C | 216 | 14.5 | 4.3 x $10^{-6}$ | 303 | 1.844 | Extreme high |
| AIN | 140-180 | 4.5 | >$10^{14}$(5x$10^{14}$) | 330 | 3.26 | High |
| Al | 237 | 23.1 | 2.82x$10^{-6}$ | 70 | 2.7 | Very low |
| Cu | 401 | 16.5 | 1.678x$10^{-6}$ | 110-128 | 8.96 | Medium |
| Al5050-O | 193 | 24.7 | 3.49x$10^{-6}$ | 68.9 | 2.69 | Low |

Based on the requirement showed in Table 2.3, aluminum is the perfect choice for the heatsink devices due to its good thermal conductivity with low density and acceptable cost.