Thermal Management of Battery for Proton Green Mobility Car

By

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Supervised by: Dr Faiz Ahmad

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

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May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AHMAD SYAFWAN BIN MOHD SAIDI

ABSTRACT

This report basically discussed about a project of designing a cooling system of battery for application of hybrid electric vehicle. Currently, the temperature of the battery will easily reach beyond the range of optimum operating temperature due to internal resistance within battery cells and climate factor. Main objective for this project is to design a cooling system that will reduce and maintain temperature of battery at minimum value. This project concentrates on designing and fabricating the battery box that can be used to reduce and maintain the temperature of battery. This project involves fabricating actual size model for the battery box that will be used to encase Lithium-ion battery. The desired result from this project is the value of battery temperature that can be reduced by using this system. The result obtained by using this cooling system showed a battery temperature that has been reduced in the range of its optimum temperature.

ACKNOWLEDGEMENTS

The author wishes to take the opportunity to express his utmost gratitude to the individual and parties that have contributed their time and efforts in assisting the author in completing the project. Without their help and cooperation, no doubt the author would face some difficulties throughout the project.

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Above all, the author would like to thank his parents, who stood beside him and encouraged him constantly. Finally, it is with the consent of the Al-mighty that everything happens as it is.

Table of Content

Content	Page

List of Figure

Content		Page

List of Table

Content **Page**

CHAPTER 1: INTRODUCTION

1.1 Project Background

Nowadays, automotive manufacturers are competing with each other in order to manufacture a vehicle that consuming less energy and good for environment. From this concept, they have come up with the idea to change the source of energy to move the vehicle from using petroleum or gasoline to electrical motor. This technology is called a hybrid electric vehicle. For conventional vehicle, it will have a conventional internal combustion engine propulsion system. For hybrid electric vehicle, it is a combination of internal combustion engine propulsion system with an electric propulsion system. The presence of electric propulsion system is intended to achieve such of objectives for hybrid electric vehicle such as better fuel economy and better performance [1]. Electric propulsion system means the system is being powered by using battery. The energy sources for hybrid electric vehicle will be a battery and gasoline but battery will be main energy source for this system. In order to directly power the electric motor, the battery will undergo a small resistance within its cell. Besides, the battery also will generate heat instead of generating energy [2]. Theoretically, electric devices cannot operate in maximum efficiency if the temperature is higher. This theory is applicable for this hybrid electric vehicle's battery system. At certain temperature, the battery's efficiency will decrease and it will affect the performance of the vehicle. In order to maintain the temperature of battery at its maximum efficiency level, a thermal management system needs to be applied and designed to this hybrid electric vehicle system. Thermal management system of the battery can be done by using high thermal conductivity material as a heat sink and air as a flow medium for this system. Besides, the density of the material cannot be neglected because it will affect the total weight of the vehicle. For this project, the temperature of battery and total weight of the vehicle need to be taking care of because these two elements are the most important criteria in order to undergo challenge events which are farthest distance challenge, quarter mile acceleration challenge, fastest time for 2-laps challenge and maximum velocity challenge. The least total weight including a driver will give more advantages for each challenge because the highest total weight of the vehicle will cause the usage of highest energy. If highest energy has been consumed, the farthest distance cannot be reached. The better thermal management of battery is strictly needed for every challenge events.

However, for quarter mile acceleration challenge or drag race challenge, the ability of the system to remove heat produced by battery is highly required.

1.2 Problem Statement

The hybrid electric vehicle is using battery packs such as Lithium-ion battery in order to reduce the amount of petroleum consumed. The advantages of using Lithium-ion battery instead of using petroleum are this system has greater performance and energy density [2]. Besides, this system is environmental friendly and can reduce the rate of air pollution cause by carbon monoxide generated by conventional vehicles. The usage of the battery also will reduce the size of the compartment that will be used to place this battery because it is highly compact physical dimension [3]. This kind of battery also has a long lifespan. The manufacturer must ensure the lifespan of battery will last until eight to ten years because the replacement cost for the battery will be very expensive [4].

In order to prolong the lifespan of the battery , the main element that should be taking care of is the temperature of the battery . The operation of most Lithium -ion cell is limited to a temperature of 20℃ to 55℃ in which heat generation due to internal resistance and polarization is easily controllable by working with voltage window and range of charge or discharge rates recommended by manufacturer [5].

Climate factor also will affect the temperature raise of the battery. For a country that has warm climate and warm weather , it is very easy to reach 50℃ to 60℃ when operating due to weather and the resistance within the battery cells itself. So, for now, the problem is to design a system of thermal management in order to get the operating temperature of the battery will be below 60℃ by using air as a cooling medium.

This project is significant due to the increasing value of hybrid electric vehicle consumer nowadays. Even though the price for the vehicle is quite expensive compared to conventional vehicle, but people nowadays has changed their interest to own the hybrid electric vehicle due to its environmental friendly and fuel cost saving.

1.3 Objective and Scope of Study

1.3.1 Objective

The objectives of this project are to design a cooling system or thermal management system in order to keep battery for hybrid electric vehicle at minimum operating temperature. Besides, the objective of this project is to select the best material that will be used to fabricate the battery box based on its properties. The battery box will encase 13 modules of Lithium-ion batteries. The properties of material that will be used can be divided into two elements which are thermal conductivity of material and density of material.

1.3.2 Scope of Study

Generally, this research is involved in thermal management of the battery system of hybrid electric vehicle. The term of thermal management in this research will be subjected as the reduced temperature process of battery or the heat dissipating process from the battery. Heat dissipating process can be determined by calculating the heat transfer rate. Higher rate of heat transferred is required in order to reduce the operating temperature of the battery to its minimum operating temperature. The stage is divided in order to achieve the objectives of this project. The selection of material is very important stage for this project because the selected material should be high thermal conductivity because heat will be transferred by the material and been cooled by exhaust fan. This system will use conductive and convective heat transfer to dissipate heat from device. This project will involve several testing in order to achieve a good result for the operating temperature of the battery. The test will be conducted by using a 1:2 scaled dimensions prototype and data for the result will be recorded.

1.4 Project Relevant

Trend of using hybrid electric vehicle has grown significantly fast. Giant automotive manufacturer such as Honda and Toyota have been in a race of producing a better hybrid electric vehicle that is affordable and have a nice look. The increase demand of hybrid electric vehicle means the number of Lithium-ion battery also increase in market and in use. Thermal management for Lithium-ion battery will be a requirement for those automotive manufacturers in order to maintain the performance of their product at maximum efficiency. Thus, this project is relevant to be done so that the hybrid electric vehicle will operate optimally. Besides, this project is relevant to be done due to expensive price of hybrid electric vehicle battery if it needs to be replacing with a new one. So, it's relevant to have a better thermal management system of battery for hybrid electric vehicle instead of replacing the battery with a new one.

1.5 Project Feasibility

The time of the project to be completed is 9 months which divided into 2 semesters but the prototype of this project should be done within short period in order to take part in competition. Besides, in order to ensure the successfulness of the project, the experimentation for the prototype should be conducted and the analysis should be done within the given time frame. With spending some times to read journals related to topic and understand the topic properly, this project should be successful. 9 months time frame should be sufficient to complete the project including all the reports that should be submitted. The process to fabricate the prototype will start immediately after the selection of the design. At the end of this time frame, the prototype and real model of battery box for thermal management system should be completed and well-operated. Some modification or improvement to the design will easily be conducted due to the availability of equipments and apparatus at university.

CHAPTER 2: LITERATURE REVIEW AND THEORY

2.1 Thermal Management of Battery for Hybrid Electric Vehicle

Maintaining an optimized and continuously regulated temperature necessitates an efficient thermal management system in Lithium-ion battery pack applications [6]. If the battery is operating at high temperature, the maximum efficiency of the battery will decrease and affect the performance of the vehicle. Battery temperature influences the availability of discharge power (for start up and acceleration), energy, and charge acceptance during energy recovery from regenerative braking [7]. The cooling medium for this system is air because air can be easily obtained. Even the thermal conductivity of air is lower than another coolant [8], but with large amount of air, it will be sufficient to complete the cooling process of the battery. Besides, the air in this country is quite humid because of the climate of this country.

In addition, the usage of heat sink will improve the heat transfer rate because it will involve with two (2) methods to dissipate heat from battery which are convective heat transfer and conductive heat transfer. Even though the heat transfer rate by convective heat transfer just a little compared to heat transfer rate by conductive heat transfer, but it also give a better result to support the cooling system for the battery.

The effective temperature for Lithium-ion battery is about 55℃ until 60℃ and if the operating temperature exceeds the value, it will affect the efficiency of the battery and performance of the vehicle [5]. The operating temperature of the battery will be inversely proportional with the efficiency of the battery when it is exceeds the minimum temperature range stated above. Incremental of temperature value is due to small resistance within battery cells and climate for the country.

2.2 Heat Transfer

Heat transfer is one of the main elements if temperature is needed to be reduced or increased. Heat transfer is a discipline of thermal engineering which are can be classified as conduction, convection, and radiation. For this project, conduction and convection heat transfer theory is being applied in order to dissipate heat from the battery to the surrounding. Total heat transfer rate can be determined by summing the amount of conductive and convective heat transfer. Besides, we can measure total heat transfer rate by using this formula [9].

$$q = (v \times A \times \rho) \times c_P \times (T_{battery} - T_{surrounding})$$

Where

q =*heat transfer rate (kW)*

v =*velocity of fluid (m/s)*

A =*Area* (m^2)

ρ =*density of air* (kg/m^3)

c_p =*specific heat capacity (kJ/kg.K)*

The formula above is assumed to obtained total heat transfer from conduction and convection. This formula will be used and integrated in order to obtain the temperature of the heat sink and temperature of the battery.

2.3 Convective Heat Transfer

Convective heat transfer is the transfer of heat from one place to another by the movement of fluid and it may occurred by two (2) ways which are spontaneous convection and force convection [8]. For this project, the convective heat transfer occurred by force convection due to the presence of blower fan. This fan will be used to channel air from the inlet of the battery box and going through the gap at between of each battery.

Convective heat transfer will be applied in order to remove the heat from heat sink material to surrounding. So, the heat transfer area for convective heat transfer is the same area of heat sink material.

The governing equation to determine the heat transfer rate by convective heat transfer has been shown below [10].

$$P = q = hA\,(T - T_0)$$

Where

q =*rate at which heat is transferred*

h =*convection heat-transfer coefficient*

A =*heat transfer area* (m^2)

T =*temperature of the immersed object* ($℃$ *or* K)

T_0 =*temperature of convecting fluid* ($℃$ *or* K)

Besides, the convection heat transfer coefficient can be obtained by using this formula [10].

$$h = 10.45 - v + 10\sqrt{v}$$

Where

h = *convection heat-transfer coefficient*

v =*speed of fluid around the object (m/s)*

Although the formula to calculate the convection heat transfer coefficient has been provided, the value of *h* can be taken from this range of value stated in the table below;

Type of Convection	Heat Transfer Coefficient
Free Convection – Air	5 - 25 (W/m^2K)
Free Convection – Water	20 - 100 (W/m^2K)
Free Convection – Air	10 - 200 (W/m^2K)
Force Convection – Water	50 - 10.000 (W/m^2K)
Boiling Water	3.000 - 100.000 (W/m^2K)
Condensing Water Vapor	5.000 - 100.000 (W/m^2K)

Table 2.1: Heat transfer coefficient

2.4 <u>Conductive Heat Transfer</u>

Conductive heat transfer is a mode of transfer of energy within and between bodies of matter, due to a temperature gradient [12]. Commonly, conductive heat transfer will involve the usage of heat sink and it will have a direct contact between the bodies of two (2) different materials that have a temperature gradient. Temperature gradient is a physical quantity that describes in which direction and at what rate the temperature changes the most rapidly around a particular location [13]. For this project, the conductive heat transfer occurred at the point of contact between the bodies of battery and the heat sink walls. In this case, the contact area of the battery bodies will be outside walls of the battery.

The governing equation to determine the heat transfer rate by conductive heat transfer has been shown below [14].

$$P = \frac{dQ}{dt} = q = KA\, dT/s$$

Where

$P = \frac{dQ}{dt}$ =*rate at which heat is transferred*

K =*thermal conductivity of material (heat sink) (*W/m.K *or W/m* ^oC*)*

A =*heat transfer area* (m^2)

dT =*temperature different across the material (K or* ^oC*)*

s =*material thickness (m)*

2.5 Existing Cooling System of Battery for Hybrid Electric Vehicle

2.5.1 Phase Change Material

Phase change materials (PCM) is a substance or material with a high heat of fusion which melting and solidifying at a certain temperature and capable of storing and releasing large amounts of energy [15]. Heat will be absorbed or released when the material changes from solid to liquid and vice versa. Thermal management using phase change material eliminates to the need for additional cooling system and improves the power use. The theory of phase change material in order to cool the battery is very simple. The material with certain melting temperature will be installed within the battery.

For example , if we want to maintain the operating temperature of the battery at 48℃, Sodium Silicate ($Na_2SiO_3 \cdot 5H_2O$) will be used as phase change material because the melting point of Sodium Silicate is at 48℃. Sodium Silicate will be melted when the temperature of the battery achieving 48℃ and during the phase change of Sodium Silicate, it will absorb large amount of heat that been generated by battery [16]. In principle, during discharge of the battery, the heat generated could be absorbed by the PCM integrated in between the cells of the battery. PCM will act as a heat sink absorbing the heat generated by battery. Due to high latent heat of the PCM, it will prevent the temperature of the battery rising sharply. There are pros and cons for this cooling method and some modification can be done in order to obtain the best cooling system for hybrid electric vehicle battery.

There is a thermo-physical property of PCM/ Graphite composite that commonly used as phase-change material for hybrid electric vehicle battery in order to maintain the temperature of the battery to achieve minimum performance and efficiency [17].

Thermo-physical properties of PCM/Graphite composite	
Property	**Units**
Thermal Conductivity…………………	16.6 W/m.K
Latent Heat…………………………..	185 kJ/kg
Specific Heat ………………………...	1.98 kJ/kg.K
Bulk Density of composites………….....	789 kg/m^3
Bulk Density of Graphite………..........	210 kg/m^3

Table 2.2: Thermo-physical properties of PCM

The advantages of this method are high volumetric latent heat storage capacity, availability and low cost, sharp melting point, high thermal conductivity and high heat of fusion [14]. The disadvantages of this method are change of volume is very high, super cooling is major in solid-liquid transition, and nucleating agents are needed and they often become inoperative after repeated cycling [15].

There is a modification that can be done to this system in order to improve this cooling system. Combining PCM with air cooled system would be most beneficial in a battery system with large format and high power cells [17]. This combination will help to speed up the heat removal from battery system and would be required to handle steady heat generation during long periods of continuous charge sustaining hybrid electric vehicle battery cycling.

2.5.2 <u>Air Cooling System</u>

There are two main type of existing cooling system for hybrid electric vehicle or to be specific cooling system for Lithium-ion battery. For the first one, cooling system by using cooled air [3]. Compared with the design as stated above, this type of cooling system will use air conditioned air as cooling medium. This air taken directly from the vehicle cabin or generated using an air conditioning unit installed specifically for the battery. Practically, this type of system can be used to control the temperature of Lithium-ion battery but it will consume a lot of energy in order to run the air conditioning. Besides, this system will be highly cost in order to install the air conditioning and this system also needs a large space to place the air conditioning unit.

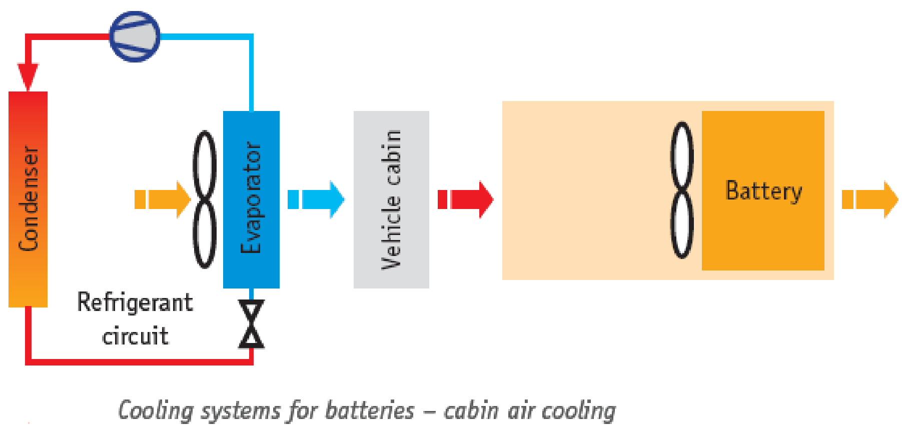

Figure 2.1: Cabin air cooling system

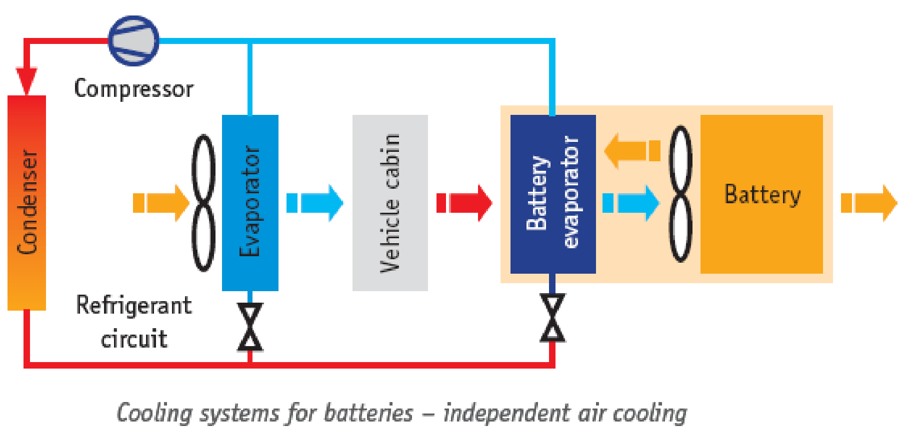

Figure 2.2: Independent air cooling system

Another type of existing cooling system for Lithium-ion battery is by using supplementary evaporator in the form of cooling plate installed within the battery [3]. The battery cells are assembled in the cooling plate. The application of this system has a similarity with the design stated above which is the application of heat sink. The different between these two systems is the heat sink for this system need to be cooled every time to maintain the temperature of the Lithium-ion battery. As stated above, the conceptual design for this project will use exhaust fan to remove the heat from heat sink during operating. Hence, it is important to select the best material that will be used as heat sink such as material with high thermal conductivity instead of availability and cost.

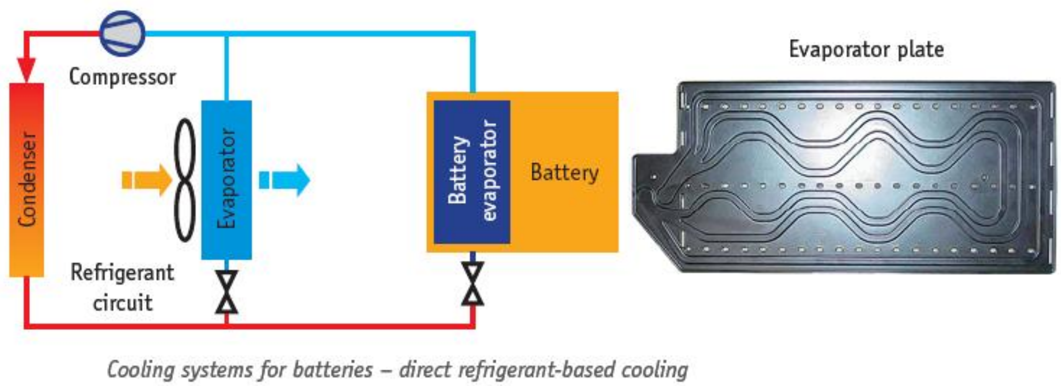

Figure 2.3: Direct refrigerant-based cooling

2.6 Theory of Thermal Management for Hybrid Electric Vehicle Battery

The theory for this project is very simple which is to control the temperature of the battery at minimum temperature in order to achieve maximum efficiency by using fresh air as a cooling medium [3]. This project will focus on designing a thermal management system in form of battery box that will be used to encase the battery pack. This system will be cooling only system because the objective is to reduce the temperature of the battery to its minimum temperature. The used of fresh air is due to availability of large amount of fresh air especially when the vehicle is moving. Besides, the usage of blower fan will enhance the flow of air from outside of the battery box and used to reduce the temperature of the battery to its minimum temperature. As being briefed, the battery pack will be placed inside the trunk of the vehicle. There will be two slots for air flow which is one for the fresh air inlet and another one is for hot air outlet. Theoretically, there will be no problem to get an air flow in and out of the trunk of the vehicle due to pressure different. For air inlet slot, while the vehicle is moving, the pressure inside the trunk will be lower than the pressure outside the trunk. So, air will flow into the trunk through the air inlet slot. With the presence of blower fan, the flow rate of air can be assumed as uniform for this system. In the beginning, there will be an exhaust fan that will be used to remove the hot air from this system. Due to energy saving, the exhaust fan has been removed and there will be enough with the presence of blower fan only. The objective of using blower fan is to speed up the flow of air from outside and give a uniform flow of air for this system. This system will use conduction and convection to dissipate heat from the battery. Blower fan also will act as a cooler for heat sink instead of removing the hot air and channeling the cool air from outside.

CHAPTER 3: METHODOLOGY

3.1 Project Activities

For this project, I have divided the task into several stages in order to complete this project within the time given. I have divided the task into data acquisition, design preparation, material selection, prototype fabrication, prototype experimentation, model fabrication, and result analysis. As stated before, the objectives of this project are to design a thermal management system or cooling system for Lithium-ion battery that will be used as energy source for hybrid electric vehicle. This design should be in form of battery box and used a material that has the best properties such as high thermal conductivity and low density.

Besides, the objective of this project is to select the best material that has high thermal conductivity and low density. High thermal conductivity material is important due to increase the heat transfer rate in order to reduce the temperature of the battery. For this project, I will compare the result of using Aluminum and Copper. This material will act as a heat sink that will allow heat to be dissipated from the battery. Besides, the heat sink material should have a lower density in order to reduce the total weight of the vehicle. If the total weight of vehicle is higher, the required energy to move or operate the car will be higher. Even the battery box doesn't contribute a lot of weight, but it is still needed for us to control the weight of the battery box to ensure that energy from the battery can fully utilized to operate the vehicle.

3.1.1 Data Acquisition

Firstly research, collect and summarized data from the theoretical studies related to hybrid electric vehicle especially in thermal management for Lithium-ion battery, the cooling process of the battery and existing system for cooling system is a task in data collection stages. At this stage, literature sources such as experimental studies, journals and reference books regarding concept and theory of thermal management system for Lithium-ion battery, diagnose the common practice techniques also contribute information to this project.

Besides, the discharge rate of the battery, capacity of the battery, and all data about the battery including the dimension of the battery has been recorded since the battery for the vehicle has been delivered by Proton. The battery box will encase the battery pack that will consist of 13 modules and each module has a dimension of 54mm (W) × 180mm (H) × 360mm (L).

In this stage, I have conducted an experiment to observe the temperature rise of the battery that will be used in this project. The objective of this experiment is to observe the temperature rise of the battery under certain condition or environment. This experiment has used ceramic conductor that will control the internal resistance of the battery. For this experiment, the resistance of the battery has been varying with two (2) values which are 6 Ohm and 9 Ohm. Besides, there are another apparatus that been used in conducting this experiment such as thermocouple and data logger.

Thermocouple and data logger has been placed at three (3) different points which are inside the battery and at both walls of the battery. Unluckily, the result for this experiment has shown some error due to surrounding and environment condition. This experiment has been conducted in a laboratory that fully equipped with air-conditioner. So, there will be a different ambient temperature which is recorded averagely as 24℃. The environment or condition during this experiment conducted will be differed with the condition at Sepang International Circuit which is has an ambient temperature averagely about 32℃ to 35℃. The data has been recorded by using data logger and the plot of time again temperature has been shown at Result and Discussion section.

Figure 3.1: Lithium-ion Battery for HEV (1 Module)

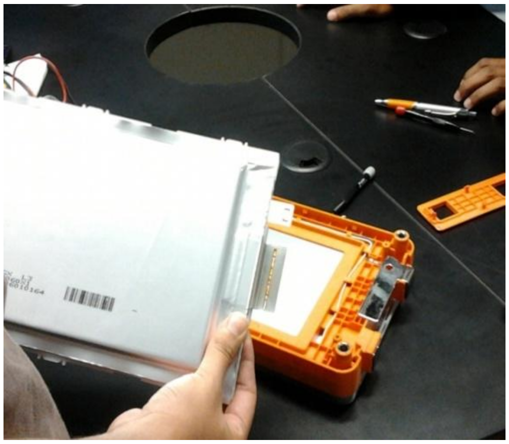

Figure 3.2: Lithium-ion Battery on the inside (1 Module)

Figure 3.3: Side view of Lithium-ion Battery (1 Module)

3.1.2 Design Preparation

Next, there will be a design preparation stage for the battery box. At this stage, the knowledge about engineering software such as Catia V5 has been fully utilized in order to prepare the design of the battery box. I have prepared two (2) designs for the battery box and it has been approved by PGMC supervisor. I have prepared the drawing of the design with an actual dimension and 1:2 scale dimensions. This 1:2 scale dimensions of drawing is for the prototype fabrication purpose. For my first design, I have prepared a pyramid shape battery box.

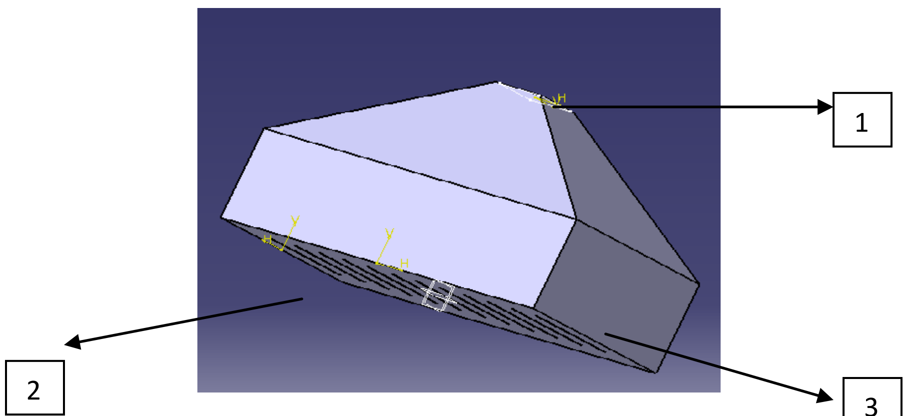

Figure 3.4: Pyramid Shape Battery Box

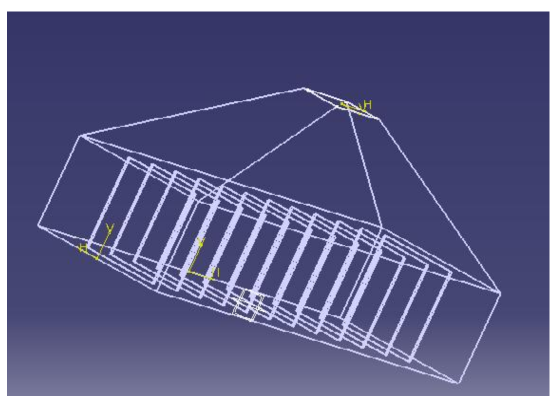

Figure 3.5: Pyramid Shape Battery Box (Wireframe)

Labels:

1. Suction fan for air outlet
2. Air inlet
3. Battery box (54mm x 180mm x 360mm) x 13 pieces

This design is used an application of hot air balloon. The theory stated that hot air has a lower density than cold air and it will go up to highest point. The highest point for this pyramid box is at the suction fan. So, it will be easier to remove the hot air to surrounding. There are some problems of using or fabricating this battery box. First, it will need a lot of space on a latitude direction because the battery will be placed in the car trunk that only has a maximum height of 500mm. The height of the battery box will reach maximally 400mm. So, it will be just a small space for the air circulation outside of the box. Besides, this design is difficult to fabricate due to its shape. I have prepared the 1:2 scales drawing for this design in order to make it as prototype.

By using laser cutter, I have cut the Perspex (2.5mm thick) based on the dimension of the drawing. The problem occurred during the assembly of the Perspex piece in order to form a pyramid box.

Besides, I have prepared another design and this design has been choose as a finalize design for the battery box. This design has a shape of semi-diffuser. This design will applied the theory of convective and conductive heat transfer due to the present of heat sink and blower fan. This design of battery box has been approved due to its space saving shape. Furthermore, this shape of battery box will allow the air to flow from inlet and going out of the battery box through the gap between each battery. The gap has been measured and the dimension of the gap is 4mm.

This design will have 2 fans which are blower fan at the inlet and exhaust fan at the outlet. Actually, the blower fan will be the one that fully operating for this system while exhaust fan will be used in case of emergency and for standby if any problem occurred to the blower fan. Blower fan will direct the air outside the box into the battery box. After measuring the flow rate of air from the blower fan used, I managed to obtain the reading of 10 m/s for the flow rate.

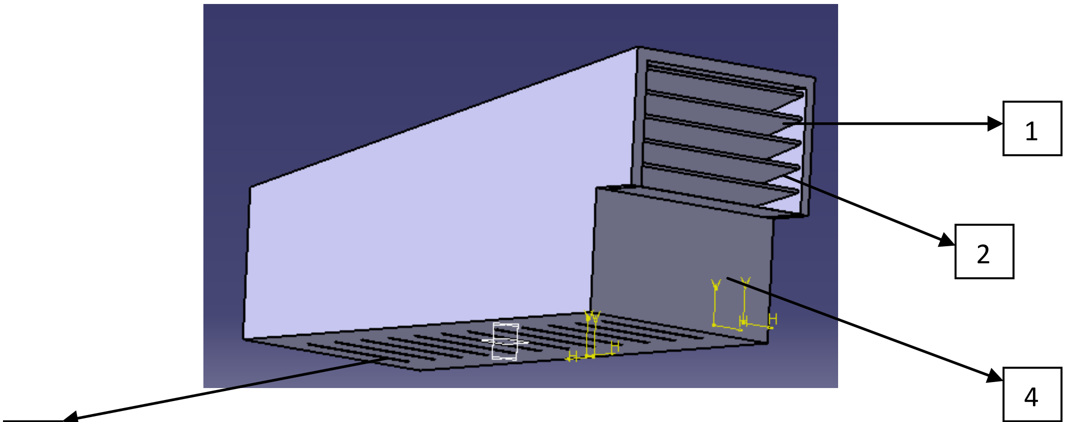

Figure 3.6: Semi-diffuser shape battery box

Labels:

1. Cold Air Inlet
2. Fins
3. Hot Air Outlet
4. Battery box (54mm x 180mm x 360mm) x 13 pieces

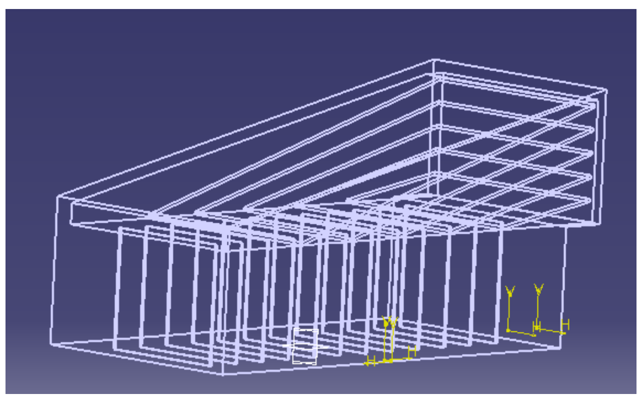

Figure 3.7: Semi-diffuser shape battery box (Wireframe)

This semi-diffuser design has more improvement than the pyramid shape battery box because this design has been added fins that will focus the flow of air directly to batteries. Besides, the presence of the fins will improve the uniform flow of air toward the batteries. Uniform flow of air is important in order to obtain a uniform temperature reduced.

3.1.3 <u>Material Selection</u>

As for material selection, I am choosing to use Aluminum. This material is well known with its high thermal conductivity which is important to be as a battery box. Actually, there are some other material that can be used instead of using Aluminum like Silver and Copper which is also a high thermal conductivity material. But there is a problem of using Silver which is the price for the silver is quite expensive compared to Aluminum.

Copper is a good thermal conductor compared to Aluminum but its density which is about three (3) times higher than Aluminum makes it not being chosen as the best material for the battery box. To show the comparison between Aluminum and Copper, I have made some calculation regarding the weight of battery box with using both materials and the reduced temperature of battery by using both materials.

3.1.4 <u>Prototype Fabrication</u>

After finishing with design preparation, I have proceeded with prototype fabrication. At this stage, I should fabricate two prototypes following both designs that I have prepared before. I have started my prototype fabrication with semi-diffuser shape of battery box. For this design, the prototype has been made by using Perspex (2.5mm thick) for the bottom part which are consist of 13 pieces of battery that has been downscale by 2 from its actual dimension.

Figure 3.8: Arrangement of Battery inside Battery Box

For the top part, the semi-diffuser shape has been done by using an Aluminum sheet (approximately about 2mm thick). Aluminum is well-known as a material that has high thermal conductivity and lower density. Besides, Aluminum sheet will easily being shaped into required design.

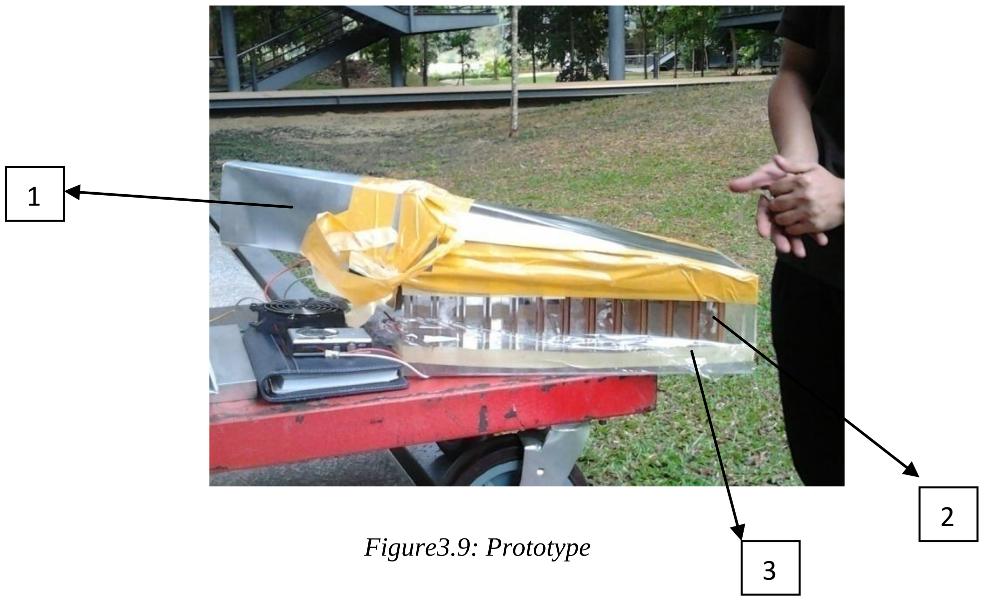

Figure3.9: Prototype

Labels:

1. Blower fan at inlet
2. 1:2 Scale battery box (90mm x 180mm x 351mm)
3. Air outlet

3.1.5 <u>Prototype Experimentation</u>

After measuring the air flow rate from the blower, we manage to get about 10 m/s of air and it doesn't consume much energy to operate the blower fan. This design has been improved from using 2 fans which is blower fan at inlet and suction fan at outlet into just 1 fan which is a blower at the inlet. Suction fan at outlet will be used as standby in case of emergency or problem occurred to blower fan. This improvement has been made due to energy management system that needs to minimize the usage of energy from battery for other purposes except for generating power for the vehicle.

By using the prototype, I have conducted experiment in order to ensure that the entire gap between each battery will receive and allow air to flow in between. The main objective of this experiment is to observe the air flow from inlet and going out at outlet. I have used a 1:2 scales blower fan and smoke generator to run the experiment. Smoke from smoke generator indicates an air that will flow from the inlet to the outlet by passing through each gap in between each battery. The video of the experimentation has been recorded. Besides, we have focused at each gap in between each battery and we manage to get all the smoke flows at each gap before exit the system. This video has been shown to PGMC Supervisor and he satisfied with this early result because we manage to make the air to flow at each gap between the batteries.

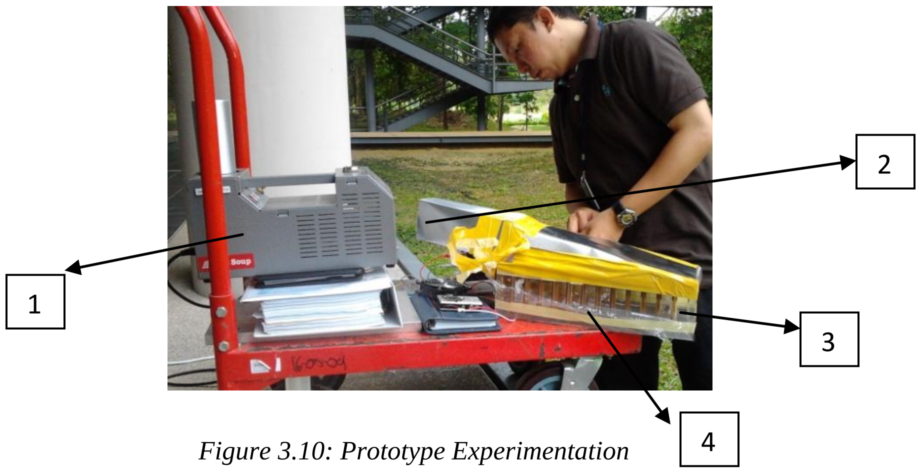

Figure 3.10: Prototype Experimentation

Labels:

1. Smoke generator
2. Blower fan at inlet
3. 1:2 Scale battery box (90mm x 180mm x 351mm)
4. Air outlet

3.1.6 <u>Model Fabrication</u>

For this project, it required me to fabricate the actual size of battery box that will be used to case the 13 pieces of Lithium-ion batteries. This box will be located inside the trunk of the vehicle. By using Aluminum plate with thickness of ½ inches or 12.7mm, the box is completely done.

There is some difficulty occurred especially during the time to attach the fins to battery box. These fins need to be arranged according to its measured points. With a tolerance of ± 2 mm, there will be some try and error method in order to fit the fins in between the battery box walls.

Besides, the fins are attached or fitted in between the walls by using spot welding method. The welding process need to be done properly and carefully due to the thickness of Aluminum plate and the measured point for the fins. The fins are only welded at each of the corner and the fins are fully sealed by using epoxy resin and hardener. The fins should be fully sealed in order to obtain the uniform flow or amount of air flow through into the battery box.

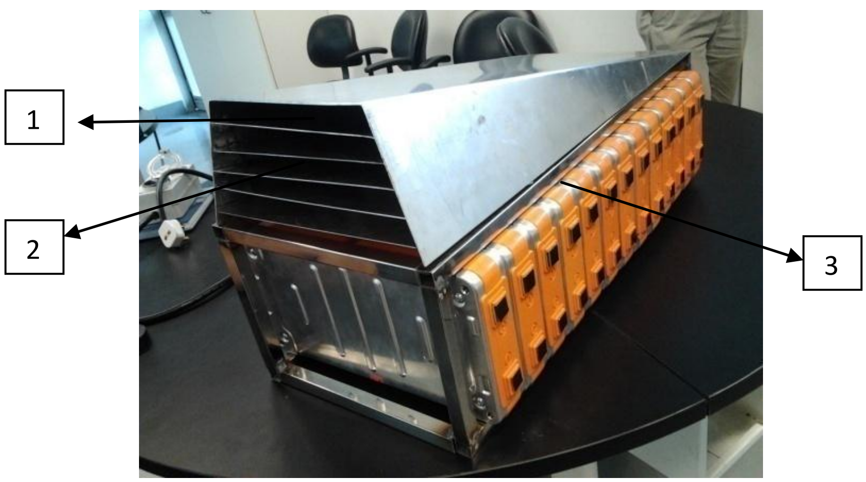

Figure 3.11: Actual size battery box with batteries

Labels:

1. Air inlet
2. Fins
3. Lithium-ions batteries (13 pieces)

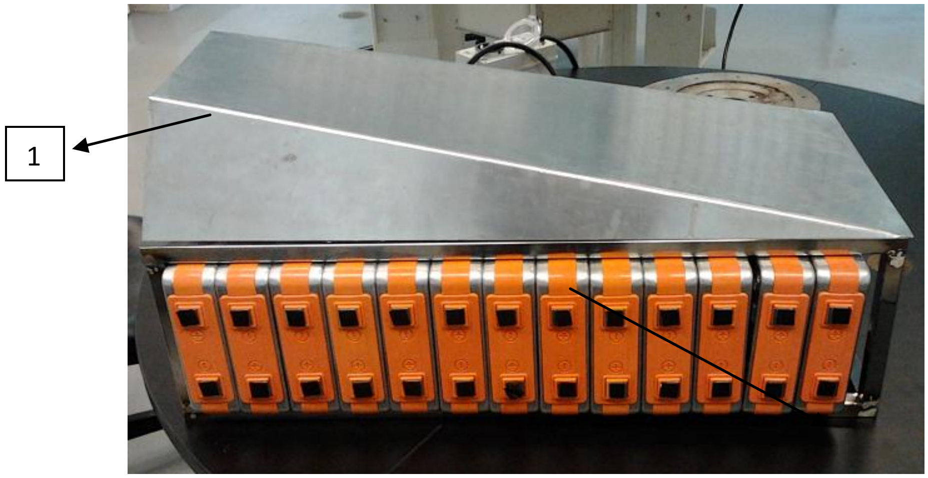

Figure 3.12: Side view of battery box

2

Labels:

1. Air inlet
2. Lithium-ions batteries (13 pieces)

3.1.7 **Result Analysis**

After finishing with the fabrication process, I have done with the result analysis for this project. The analysis for this project will focus on conduction and convection heat transfer rate by comparing between the using of two (2) different materials which is Copper and Aluminum. Besides, I also prepared an analysis in form of weight comparison of Aluminum and Copper due to the selected design.

3.2 Report Flowchart

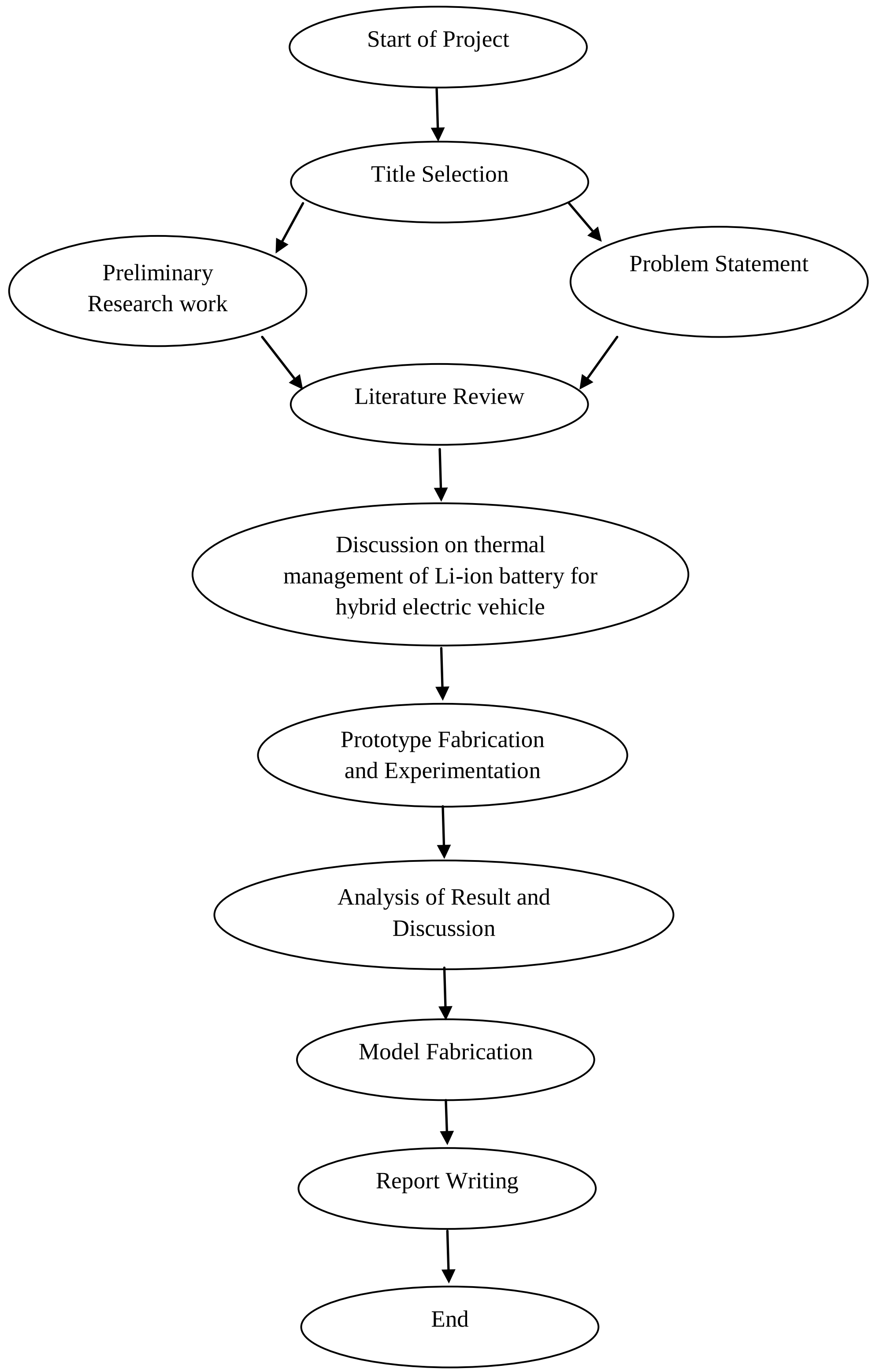

Figure 3.13: Report Flowchart

3.3 <u>Project Flowchart</u>

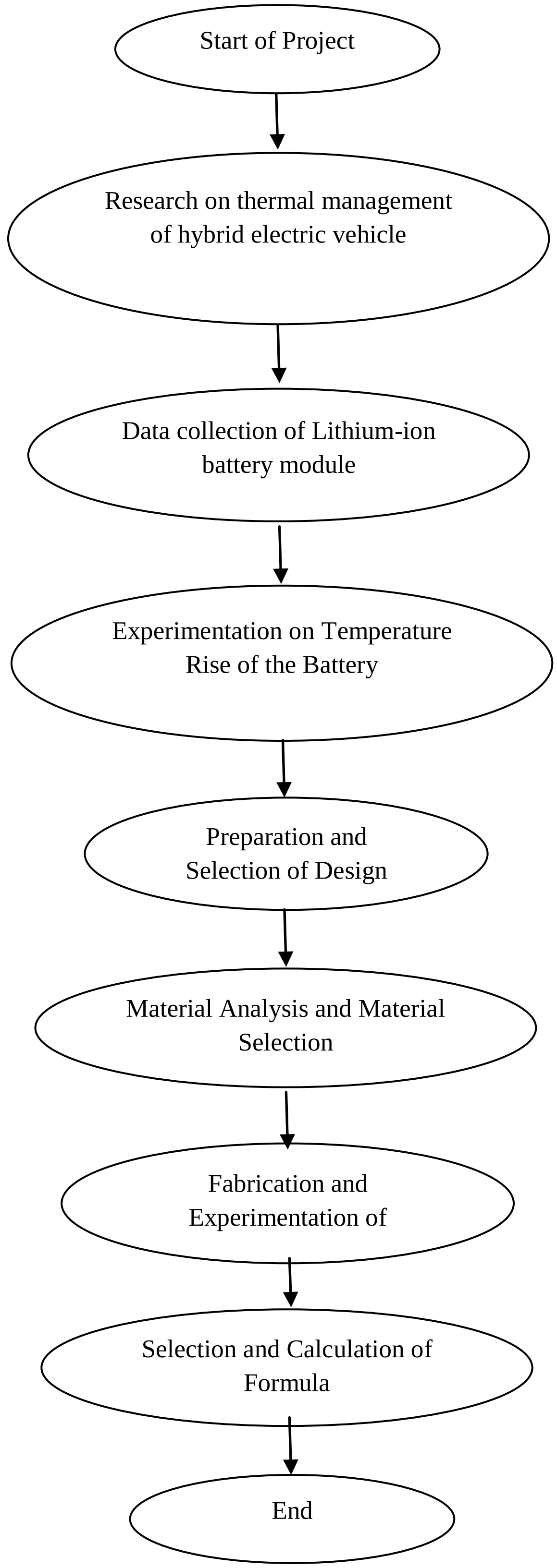

Figure 3.14: Project Flowchart

3.4 Project Timeline

3.4.1 Final Year Project 1 Timeline

No	Details/Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of FYP topic title								MIDSEMESTER BREAK							
2	Preliminary Research Work															
3	Submission of Preliminary Report															
4	Study on Lithium-ion Battery Working Principles															
5	Study on Conceptual Design for Cooling System															
6	Proposal Defence															
7	Study on Material Properties															
8	Selection of Design for Cooling System															
9	Selection of Material															
10	Preparation for Interim Report															
11	Submission of Interim Draft Report															
12	Submission of Interim Report															

Figure 3.15 FYP1 Timeline

3.4.2 Final Year Project 2 Timeline

No	Details/Weeks	1	2	3	4	5	6	7	MID SEMESTER BREAK	8	9	10	11	12	13	14
1	PGMC Weekly Meeting	■	■	■	■	■	■	■		■	■	■	■	■	■	■
2	Experimentation on temperature rise of the battery	■														
3	Preparation and Selection of Design		■	■												
4	Material Analysis and Selection		■	■												
5	Fabrication of Prototype				■	■										
6	Experimentation of Prototype				■	■										
7	Selection and Calculation of Formula						■	■								
8	Fabrication of real model for battery box										■	■				
9	Submission of Progress Report									■						
10	Pre-EDX												■			
11	Submission of Draft Report													■		
12	Submission of Dissertation (Soft Bound)													■		
13	Submission of Technical Paper														■	
14	Oral Presentation															■
	Submission of Dissertation (Hard Bound)															■

Figure 3.16: FYP2 Timeline

3.5 Tools Required

For this project, tools required and has been used in order to complete the fabricating process are cutting tool which is a laser cutter. This cutting tool has been used in this project to cut the Perspex for the prototype. This laser cutter machine has a high accuracy cutting power and it is not leaving any coarse surface at the Perspex surface. Besides, this machine is fully controlled by computer and it will cut the Perspex accurately based on the dimensions of the drawing. This tool is being used during the stage of prototype fabrication

Furthermore, there is also a needed of Shearing Cutting Machine in order to cut the metal plate that will be used as a heat sink for this battery box. Shearing Cutting Machine is required due to the thickness of the metal plate which is about ½ inches or 12.7mm. Besides, this machine will cut the plate accurately based on the dimension required. The using of spot weld machine also required in order to complete this project. These tools are being used during the stage of fabricating the model of the battery box.

Other tools that required completing this project are ceramic conductor, thermocouple, and data logger. These apparatus has been used to conduct the experiment with the objective to observe the temperature rise of the Lithium-ion battery. The experiment is being conducted in order to obtain data of the battery.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Heat transfer rate

For this project, we assume that total heat dissipated from the system which is the combination or summation of conductive and convective heat dissipate rate. By using this formula to determine total heat transfer rate, we can observe the impact of air velocity from blower fan in order to reduce the battery temperature.

$$q = (v \times A \times \rho) \times c_p \times (T_{battery} - T_{surrounding})$$

First, we take the air velocity from the blower fan to be as 10*m/s*. This value is the actual value of air velocity that can be obtained from the blower fan. For temperature different, we assumed that temperature of the battery will be at maximum value of 80℃ while temperature of surrounding is to be assumed as 30℃. This calculation is referring as using Aluminum as a heat sink.

$$q = 10m/s \times 0.253m^2 \times 1.00kg/m^3 \times 1.009kJ/kg.K \times (353K - 303K)$$

$$q = 127.64kW$$

$$q = KA\, dT/s + hA\,(T - T_0)$$

$$127.64kW = [250W/m.K \times 0.19116m^2 \times ((353K - T_{heat\ sink})/0.013m)] + [32.07W/m^2.K \times 0.19116m^2 \times (T_{heat\ sink} - 303K)]$$

$$T_{heat\ sink} = 330K \text{ or } 57℃$$

4.2 Conductive Heat Transfer Rate

For this project, there will be some calculation involved in order to determine the heat transferred by the battery through the battery box. The calculation can be divided into two (2) parts which are for conductive heat transfer and convective heat transfer. For conductive heat transfer, the applied region of the battery will be at the point that the battery is directly contacted with the battery box walls. In addition, the walls of battery box are fabricated by using a heat sink material. So, the heat transfer rate can be calculated by using this formula.

$$P = \frac{dQ}{dt} = q = KA\,(T_{\text{battery}} - T_{\text{heat sink}})/s$$

Where

$P = \frac{dQ}{dt}$ =*rate at which heat is transferred*

K =*thermal conductivity of material (heat sink)* (W/m.K or W/m ^oC)

A =*heat transfer area* (m^2)

dT =*temperature different across the material* (K or ^oC)

s =*material thickness (m)*

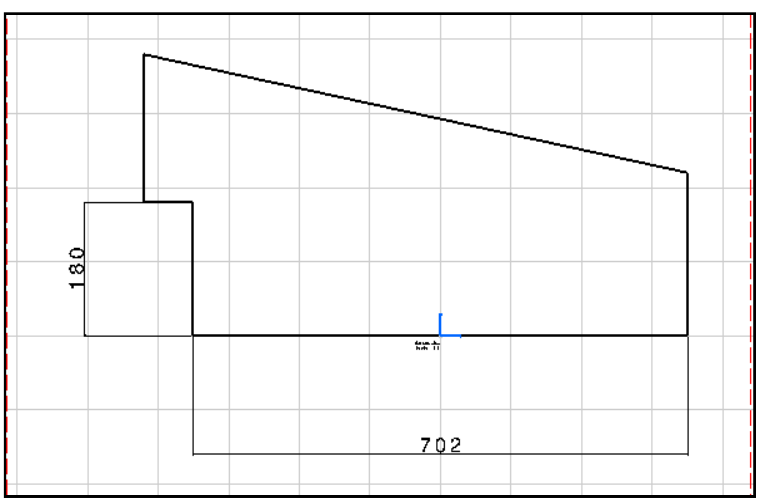

Figure 4.1: Front View of Battery Box

Heat transfer area

Heat transfer area for conductive and convective heat transfer can be determined by calculating the area of wall of battery. This value of heat transfer area is assumed to be same because conduction occurred by removing heat from battery to heat sink by contacting the wall of battery with heat sink. Besides, convection occurred in order to remove heat from heat sink to surrounding by using blower fan.

$A_1 = \frac{180mm}{1000} \times \frac{360mm}{1000} = 0.06480m^2$

$A_2 = \frac{180mm}{1000} \times \frac{702mm}{1000} = 0.12636m^2$

Total heat transfer area=0.19116 m^2

Thermal conductivity of material

For this project, I have made an analysis of heat transfer rate by using two (2) different materials as heat sink. The material that been chosen are pure Copper and pure Aluminum. The properties of these materials have been shown in the table below.

Thermal Conductivity Of Metal			
Material / Substance	Thermal Conductivity (*W/m K*)		
	25	125	225
Aluminum	250	255	250
Copper	401	400	398

Table 4.1: Table of Thermal Properties of Metal

Temperature different across the material can be determined as temperature different between battery surface temperature and heat sink temperature. As mentioned by PGMC supervisor, temperature of the battery may reach at high temperature during quarter mile acceleration challenge (approximately 100℃). For heat sink temperature, it can be determined by measuring ambient temperature which is can be assumed to be approximately 30℃.. For material thickness, it can be obtained by measuring the thickness of the metal plate which is $\frac{1}{2}$ *inches or* $0.013m$.

q_{cond} $= 10m/s \times 0.253m^2 \times 1.00kg/m^3 \times 1.009kJ/kg.K \times (353K\text{-}330K)$

$= 58.71kW$

4.3 Convective Heat Transfer Rate

For convective heat transfer, the applied region is located at the gap between each battery. The formula for convective heat transfer and dimension of the region for convective heat transfer has been shown below.

$$P = \frac{dQ}{dt} = hA\,(T - T_0)$$

Where

$P = \frac{dQ}{dt}$ =*rate at which heat is transferred*

h =*convection heat-transfer coefficient*

A =*heat transfer area* (m^2)

T =*temperature of the immersed object* (℃ *or* K)

T_0 =*temperature of convecting fluid* (℃ *or* K)

$$h = 10.45 - v + 10\sqrt{v}$$

Where

h = *convection heat-transfer coefficient*

v =*speed of fluid around the object (m/s)*

Heat transfer coefficient

For heat transfer coefficient, it can be obtained by using formula stated above. The value of v can be obtained by measuring the flow rate of air generated by blower fan. As measured, the blower fan that will be used in this system will generate air with a flow rate of 10m/s.

$$h = 10.45 - (10) + 10\sqrt{10} = 32.07\ W/m^2K$$

The temperature of the immersed object can be obtained by measuring the temperature of the battery surface which is at the gap between each battery. So, the temperature of the battery is assumed to be approximately80℃. besides, the temperature of convecting fluid is obtained by the temperature of ambient which is assumed to be 30℃.

4.4 Calculation of Battery Temperature

Combining the equation of conduction and convection heat transfer, the temperature of the battery for the certain air velocity or flow rate of air can be obtained.

$$(v \times A \times \rho) \times c_p \times (T_{battery} - T_{surrounding}) = hA\ (T_{heatsink} - T_{surrounding}) + KA\ (T_{battery} - T_{heat\ sink})/s$$

Since heat sink temperature has been obtained earlier, there is only one (1) unknown in above equation which is the battery temperature.

$$58.71kW = 32.07(330 - 303) + (373 \times 0.19116) \times (T_{battery} - 303)/0.013$$

$$T_{battery} = 338K$$

4.5 Weight Calculation of Battery Box

However, the weight of the battery box should be calculated in order to select the best material that will be used as battery box. The density of those materials can be obtained from table of properties shown above. To get the value of weight for the battery box, the volume of material that been used need to be calculated. The thickness of the plate or heat sink that will be used has a value of $\frac{1}{2}\,inches\ or\ 0.013m$.

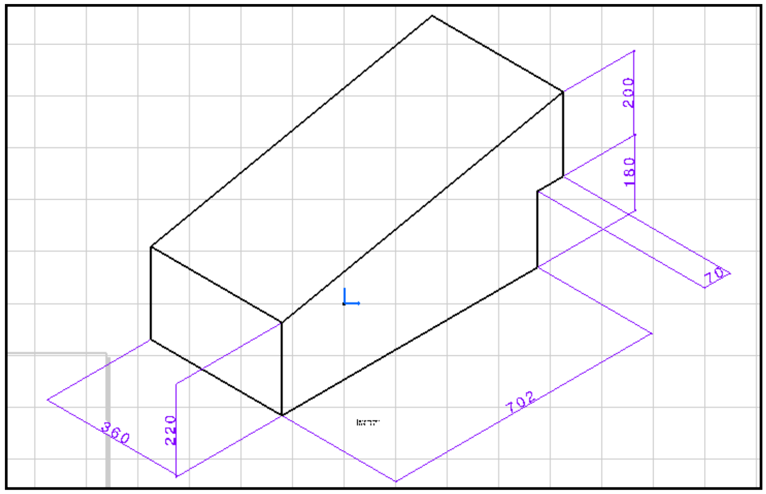

Figure 4.2: Isometric View of Battery Box

$V_1= \left(\frac{180mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) \times 2 = 0.0016848m^3$

$V_2= \left(\frac{180mm}{1000} \times \frac{702mm}{1000} \times 0.013m\right) \times 2 = 0.0032854m^3$

$V_3= \left(\frac{40mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) \times 2 = 0.0003744m^3$

$V_4= \left(\frac{40mm}{1000} \times \frac{702mm}{1000} \times 0.013m\right) \times 2 = 0.0007301m^3$

$V_5= \left(\frac{1}{2} \times \frac{160mm}{1000} \times \frac{772mm}{1000} \times 0.013m\right) \times 2 = 0.0016058m^3$

$V_6= \left(\frac{788.41mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) \times 2 = 0.0073795m^3$

Total volume of the box $=V_1+V_2+V_3+V_4+V_5+V_6= 0.01506m^3$

Besides, the volume of the fins inside the box also should be counted because the plate used has a same density and thickness as the wall of the battery box.

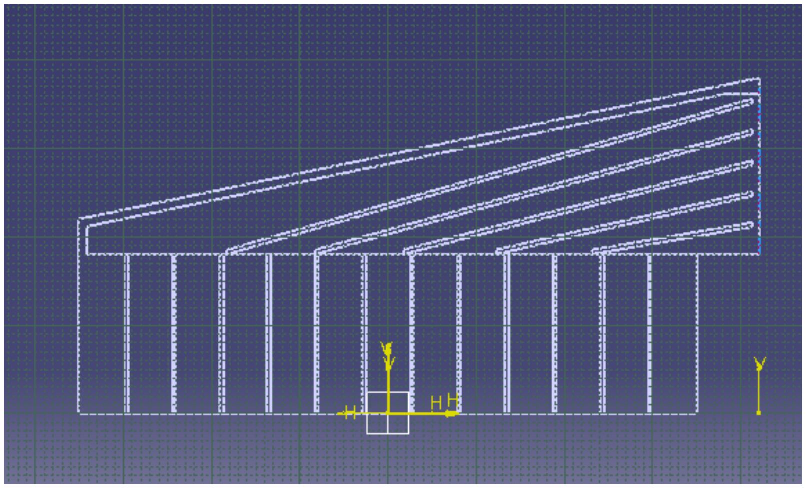

Figure 4.3: Inside view of Battery Box

Volume of fins

$V_1 = \left(\frac{112mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) = 0.000524m^3$

$V_2 = \left(\frac{224mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) = 0.001048m^3$

$V_3 = \left(\frac{336mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) = 0.001572m^3$

$V_4 = \left(\frac{448mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) = 0.002097m^3$

$V_5 = \left(\frac{560mm}{1000} \times \frac{360mm}{1000} \times 0.013m\right) = 0.002621m^3$

Total volume of fins $= V_1 + V_2 + V_3 + V_4 + V_5 = 0.007862m^3$

Total volume $= 0.01506m^3 + 0.007862m^3$

$= 0.02292\ m^3$

To obtain the weight of the battery box, the formula that can be used is shown below. For this project, I have compared the weight of the battery box by using two different materials which are pure Copper and pure Aluminum

$$\rho = m/V$$

Where

ρ =density of material (kg/m^3)

m =mass of material (kg)

V =volume of material (m^3)

<u>For pure Copper:</u>

$m = \rho V = 8933kg/m^3 \times 0.02292m^3 = 204.74kg$

<u>For pure Aluminum:</u>

$m = \rho V = 2702kg/m^3 \times 0.02292m^3 = 61.93kg$

So, the best material for fabricating battery box will be pure Aluminum due to its high rate of heat transfer while having a least weight compared to pure Copper.

4.6 Data for Experiment of Temperature Rise of Lithium-Ion Battery

As mentioned in Methodology section, I have conducted an experiment with an objective to observe the temperature rise of the Lithium-ion battery. With three (3) different points of measurement, the experiment has been successfully conducted. Unluckily, due to ambient condition and environment, the data obtained from this experiment are not accurate and cannot be used. Tabulated data has been shown below with a plot of time against temperature at three (3) different points and ambient temperature.

Time (s)	Current (Ampere)	Tambient	Tinside	Twall1	Twall2	Voltage
0	0.81	24.2	24.8	24.9	24.7	7.38
1	0.85	23.8	24.8	24.8	24.4	7.38
2	0.85	23.9	24.8	24.8	24.7	7.38
3	0.86	23.9	24.8	24.8	24.3	7.37
4	0.86	24.1	24.8	24.8	24.4	7.37
5	0.87	23.7	24.8	24.8	24.2	7.37
6	0.87	23.9	24.8	24.8	24.3	7.37
7	0.87	23.8	24.8	24.7	24.4	7.36
8	0.87	24	24.8	24.7	24.2	7.36
9	0.87	23.9	24.8	24.7	24.4	7.36
10	0.84	24	24.8	24.8	24.5	7.36
11	0.85	24.1	24.8	24.8	24.5	7.36
12	0.84	24	24.8	24.7	24.5	7.35
13	0.84	23.8	24.8	24.7	24.4	7.35
14	0.85	24	24.8	24.7	24.4	7.35
15	0.85	23.9	24.8	24.8	24.5	7.35
16	0.87	23.7	24.8	24.8	24.4	7.34
17	0.86	23.6	24.8	24.7	24.4	7.34
18	0.87	24	24.8	24.7	24.4	7.34
19	0.89	23.5	24.8	24.7	24.3	7.34
20	0.88	24.2	24.7	24.8	24.7	7.33
21	0.86	24.2	24.7	24.8	24.7	7.33
22	0.85	24.1	24.7	24.7	24.4	7.33
23	0.85	23.8	24.7	24.7	24.4	7.33
24	0.86	24.1	24.7	24.7	24.5	7.33
25	0.87	24	24.7	24.7	24.4	7.33
26	0.77	23.9	24.7	24.8	24.5	7.33
27	0.78	24.2	24.7	24.8	24.7	7.33
28	0.75	24.1	24.7	24.8	24.7	7.33

29	0.77	24.3	24.7	24.7	24.5	7.33
30	0.75	24	24.7	24.7	24.5	7.33
31	0.76	23.9	24.7	24.7	24.5	7.33
32	0.76	24.1	24.7	24.7	24.5	7.33
33	0.78	23.9	24.7	24.7	24.4	7.33
34	0.76	23.7	24.7	24.7	24.4	7.33
35	0.78	23.8	24.7	24.7	24.5	7.33
36	0.76	23.9	24.7	24.7	24.5	7.33
37	0.78	24	24.7	24.7	24.5	7.33
38	0.77	24.1	24.7	24.7	24.7	7.32
39	0.78	24.1	24.7	24.7	24.7	7.32
40	0.81	23.8	24.7	24.7	24.7	7.32
41	0.78	24.2	24.7	24.7	24.7	7.32
42	0.76	24.2	24.7	24.7	24.7	7.32
43	0.78	24	24.7	24.7	24.7	7.32
44	0.78	23.9	24.7	24.7	24.7	7.32
45	0.78	24	24.7	24.7	24.7	7.32
46	0.76	24	24.7	24.7	24.5	7.32
47	0.79	23.9	24.7	24.7	24.5	7.32
48	0.77	24	24.7	24.7	24.4	7.32
49	0.78	24.1	24.7	24.7	24.5	7.32
50	0.8	23.7	24.7	24.7	24.5	7.32
51	0.79	24	24.7	24.7	24.5	7.32
52	0.8	24.4	24.7	24.4	24.2	7.32
53	0.77	24	24.7	24.5	24.2	7.32
54	0.76	24.1	24.7	24.5	24.1	7.32
55	0.75	24	24.7	24.3	24.2	7.32
56	0.76	24.2	24.7	24.7	24	7.32
57	0.75	24.2	24.7	24.7	23.9	7.31
58	0.75	24.2	24.7	24.7	24.1	7.31
59	0.76	23.9	24.7	24.7	24	7.31
60	0.76	24.2	24.7	24.5	23.8	7.31

Table 4.2: Experiment Data for Temperature Rise of Battery

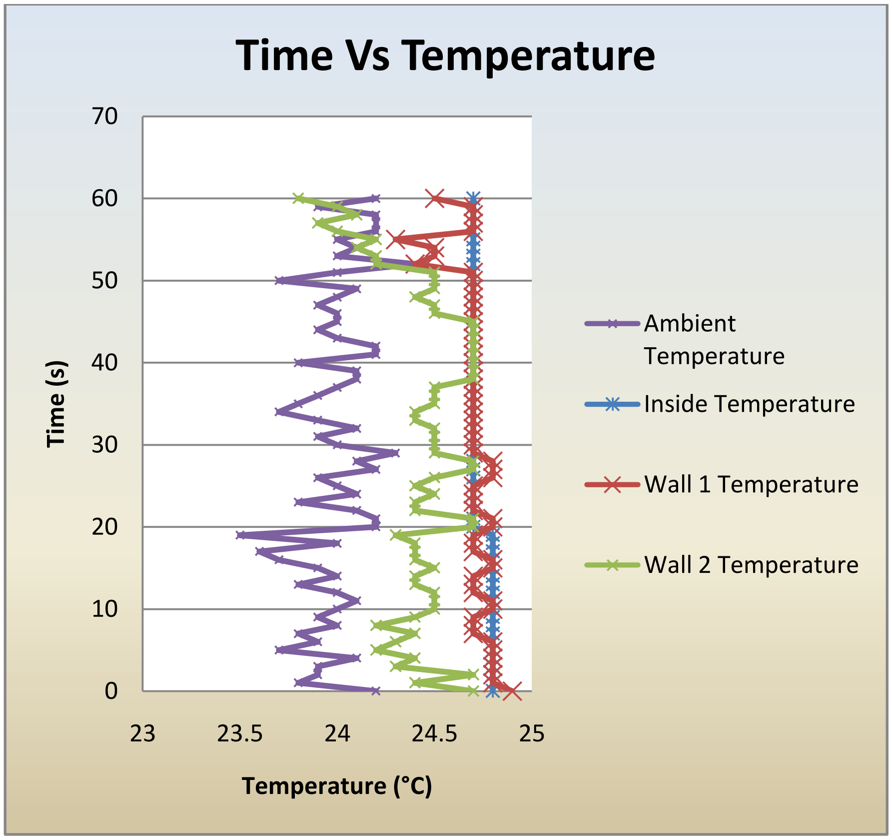

Figure 4.4: Plot of Time vs. Temperature

This graph has shown the time against temperature from the experiment that is conducted to observe the temperature rise of the battery. This data actually has shown the temperature rise during draining mode. In this mode, not much heat generated compared to regenerative and recharge mode of the battery

4.7 Battery and Heat Sink Temperature

Air Velocity (m/s)	Aluminum		Copper	
	Heat Sink Temperature	Battery Temperature	Heat Sink Temperature	Battery Temperature
0	353	353	353	353
5	341	343	343	344
10	330	338	332	335
15	318	331	321	326
20	306	324	310	317
25	294	317	299	308

Table 4.3: Data for Air Velocity and Temperature

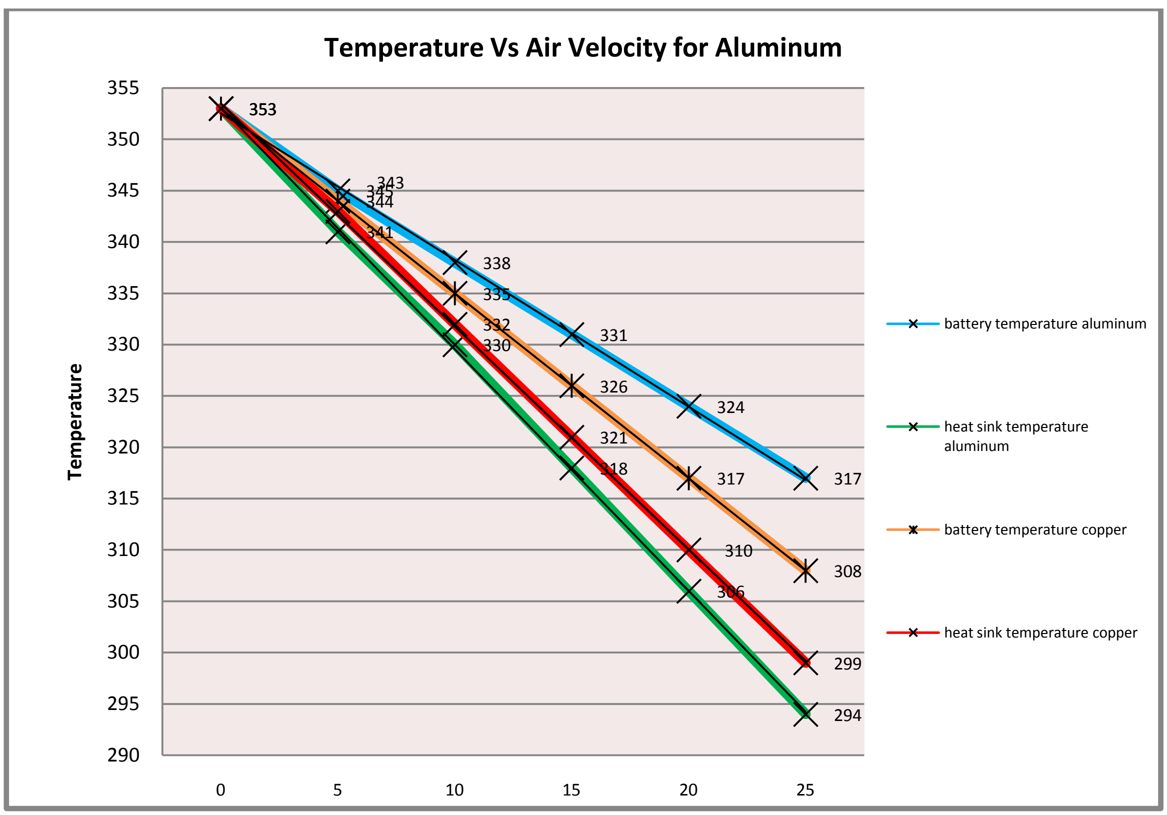

Figure 4.5: Plot of Temperature Vs Air Velocity

The graph has shown the different temperature of battery and heat sink from two different materials that being used as a heat sink or battery box. This plot actually shows the result for the effect of different thermal conductivity value and different value of air velocity from the blower fan.

From the graph, we can see that more temperature of the battery can be reduced if Copper being used as a heat sink compared to Aluminum due to its high thermal conductivity than Aluminum. Even though, Aluminum also showed a good result to be used as a heat sink due to its temperature reduced. There is only a slightly different in the value of battery temperature. Copper is well-known for its high thermal conductivity. But, instead of using Copper which is has higher density, Aluminum is the best material for this project. The effect of the thermal conductivity of material can be seen by measuring the heat transfer rate which is the conductive heat transfer rate.

We also can see the effect of air velocity against the temperature reduced of battery and heat sink. Higher value of air velocity or air flow rate, higher value of temperature can be reduced. But, higher value of air flow rate means the blower fan used will be bigger and need to consume higher energy from the battery. Besides, higher value of air velocity will increase the convection heat transfer rate. For this project, it been assumed that only force convection occurred and neglect the effect of natural convection due to the location of the battery box which is inside the trunk of the vehicle. Convection heat transfer occurred in order to remove heat from heat sink to surrounding.

4.8 <u>Weight Comparison</u>

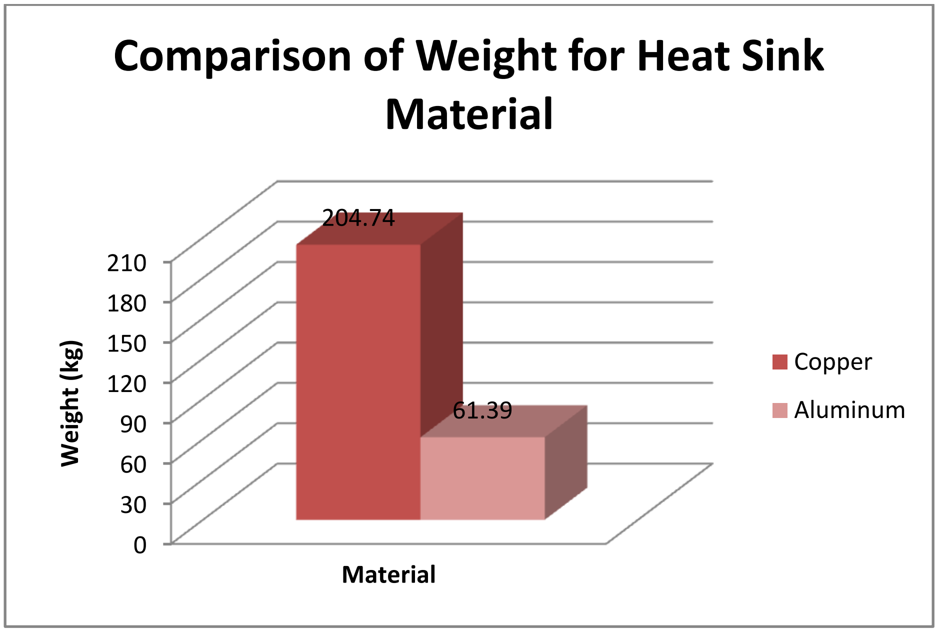

Figure 4.6: Graph of Weigh Comparison

The graph above has shown a weight comparison between Aluminum and Copper for the purpose of battery box. This comparison is important because total weight of the battery box will affect the performance of the vehicle. Higher weight of battery box will cause the vehicle weight increase and the vehicle needs to consume more energy from the battery in order to operate the vehicle. Energy from the battery should be fully utilized just to operate the vehicle or to run the motor of the vehicle instead of using it for another purposes. So, the idea to reduce the weight of the battery box will reduce the energy consumption from the battery. From the graph, we can see that weight of Aluminum is only one third of weight of Copper.

4.9 Discussion

From the experimentation by using the prototype, I found that this design of battery box is allowing the air flow from the inlet and been removed at the outlet of this design. Besides, this prototype has shown a good value of heat transfer rate especially from conductive heat transfer. With the presence of force convective heat transfer, it will enhance the heat transfer rate for this system. Force convective heat transfer can be manipulated by varying the flow rate or speed of the air. For this system, the speed of the air has been measured approximately $10m/s$. This speed or flow rate of air is needed to determine the heat transfer coefficient of air. From this experimentation, we can see that air will be focused by blower fan at the inlet of this battery box. There will be a temperature different between air inlet and outlet due to heat being removed from this system. Theoretically, air will absorb the heat generated from the battery and going out at the outlet. By looking at the properties of air, the heat capacity of air at 80℃ will be 1.009 $kJ/kg.K$. This amount of heat capacity of air has shown that air will absorb the heat generated as a cooling mechanism for this system.

From this experimentation, it also shown that suitable operating temperature for Lithium ion battery will be around 50℃ to 70℃ while the maximum temperature of the battery may reach 100℃ to 150℃ depend on the climate or surrounding condition. The condition of the surrounding can affect the temperature rise of the battery. Besides, the ambient temperature of the surrounding will be higher and the cooling system needs some modification in order to maintain the temperature at it minimum range.

The benefits from this thermal management system are it is environmental friendly compared to the usage of chemical as a coolant. Besides, this system will only use air as cooling medium and it may reduce the complexity of this design compared by using water or other fluid as cooling medium. This system also has higher operating time and maintenance cost effective compared to the using of cooling system using water. For water cooling system, the pipeline or fin used will easily corrode due to reaction with Hydrogen and Oxygen. For maintenance cost, water cooling system required more than air cooling system due to the corrosive environment by using water.

CHAPTER 5: CONCLUSION

5.1 Conclusion

As a conclusion, this project is successfully met its objective which are to design the thermal management system that will reduce the battery temperature to its minimum value. From the graph shown, we can see that the temperature of the battery is successfully reduced to the range of optimum operating temperature of Lithium-ion battery which is in the range of 20℃ to 55℃. Even though this system is only using air as a transfer medium or cooling medium, it shown that battery temperature can be maintained within the range of the optimum temperature.

Besides, this project also has successfully met another objective of this project which is to select the best material based on its properties. The properties of material in this project are strictly referred to thermal conductivity and density. The battery box should have high thermal conductivity and low density. As Aluminum being chosen to be used as battery box, it show that Aluminum have a high thermal conductivity and low density. High thermal conductivity of the material has an effect on temperature reduced of the battery which is can be seen in the graph of temperature against air velocity.

Furthermore, density of the material will affect the total weight of the battery box. As shown in the graph of weight comparison, Aluminum has only one third (1/3) of total weight compared to Copper. So, all objectives for this project are successfully met at the end of this project.

5.2 Recommendation

For recommendation, this system should be designed by using a material that has high thermal conductivity and low density. These two parameters are important in designing this cooling system. We may used composite such as Metal Matrix Composite material instead of using pure Copper or pure Aluminum. Metal Matrix Composite is a good material which is has high thermal conductivity and low density compared to pure metal. The presence of fiber such as glass fiber or carbon fiber that has high thermal conductivity and low density will increase the heat transfer rate for this system. By using the rule of mixture, we manage to determine the density of the composite and we can see the reduction of density for composite material compared to pure metal.

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