A
Project Report
On

Thermal Management for Electric Two Wheelers

submitted to

Sant Gadge Baba Amravati University,
Amravati (M.S.) 444 602

in partial fulfillment of the requirement

for the degree of

BACHELOR OF ENGINEERING
in
MECHANICAL ENGINEERING

by

Varun Jayant Kukadkar

Mitali Dinesh Bele

Kartik Sunil Jadhao

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Ajay Devche

under the guidance of

Prof./Dr. M. B. Bhambere

Department of Mechanical Engineering
Shri Sant Gajanan Maharaj College of Engineering
Shegaon-444203 (M.S.)
(Recognised by AICTE, accredited by NBA, New Delhi, NAAC, Banglore & ISO 9001:2000)
www.ssgmce.ac.in

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Certificate

This is to certify that the project report entitled **"Thermal Managementfor Electric Two Wheelers"** is hereby approved as a creditable study carried out and presented by

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in manner satisfactory to warrant of its acceptance as a pre-requisite in a partial fulfillment of the requirements for the degree of Bachelor of Engineering in Mechanical Engineering of Sant Gadge Baba Amravati University, Amravati during the **Session 2022-23.**

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– Projectees

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Abstract

Internal combustion engines that use conventional fuels are significant contributors to carbon emissions, which result in environmental degradation.Electric Vehicles (EVs) are a more efficient and cost-effective solution to this issue, especially if the battery charging is done using renewable energy conversion-based routes instead of conventional-based routes. The use of renewable energy to power EVs can reduce carbon emissions and air pollution.EVs use lithium-ion batteries for energy storage, but these batteries face many challenges. The low efficiency at extreme temperatures is one of the significant challenges that limit the performance and range of EVs. Additionally, the decreased electrode life at high temperatures and safety concerns related to thermal runaway are other challenges. These challenges directly affect the vehicle's performance, reliability, cost, and safety. The batteries can be fatally destroyed due to overheating caused by electrons' movements during the charging and discharging process in elevated temperatures. Therefore, an effective battery thermal management system (BTMS) is critical to the success of electric vehicles in the long term.

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INTRODUCTION

CHAPTER 1

Introduction

1.1 Overview

Electrochemical batteries have become an indispensable part of our lives since they were first invented by Alessandro Volta in 1800. There are two main types of electrochemical batteries, namely primary and secondary batteries. Primary batteries are single-use and cannot be recharged, whereas secondary batteries, also known as rechargeable batteries, can be reused cyclically. Primary batteries, such as zinc-carbon batteries, constitute a significant portion of the commercialbattery market. However, their use poses various challenges such as the generation of unrecyclable materials and toxic components that can be detrimental to the environment. As a result, the development of secondary batteries has risen rapidly, including nickel-metal hydride batteries, sodium-ion batteries, and lithium-ion batteries (LIBs). LIBs are currently the leading secondary battery in the market due to their high energy density, excellent performance, and a wide range of applications.

The typical Lithium-ion battery (LIB) comprises a cathode based on a lithium compound, an anode based on carbon, an electrolyte, and a separator. Usually, cathode materials are coated onto an aluminium foil, and anode materials are coated onto a copper foil. These metals act as current collectors. The separator, a porous polymer, is soaked in the electrolyte and placed between the anode and cathode to prevent electrode shorting. Lithium ions shuttle through the electrolyte as charge carriers, going through intercalation and deintercalation cycles. Redox reactions occur at the electrodes, generating electrons that move unidirectionally through the external circuit to produce the current. Equations (1) and (2) describe the redox reactions that occur at the LiFePO4 cathodes and carbonanodes during discharge, respectively.

$$xLi^{+} + Fe^{3+}PO_4 + (1-x)LiFe^{2+}PO_4 + xe^{-} \rightarrow LiFe^{2+}PO$$

$$Li_xC_6 \rightarrow Li^{+} + C_6 + xe^{-}$$

Lithium-ion batteries (LIBs) operate by the migration of lithium ions in the internal circuit and electrons in the external circuit. This movement of charge carriers is known as the C rate, which refers to the charging or discharging current divided by the capacity of the LIBs. With their high energy density of up to 705 Wh/L and power density of up to 10,000 W/L, along with their high voltage capability and great cycling performance, LIBs have found widespread use as power sources in a wide range of applications. These include electronic products, electric vehicles, energy storage systems, military and aerospace applications, and many more.

1.2 Background and significance of Problem

Despite their many benefits, LIBs still face several barriers that limit their application space. One of the major limitations is the impact of temperature on the proper operation of the batteries. The acceptable temperature range for LIBs is typically between -20°C and 60°C, with study indicating that the optimal temperature range is between 15°C and 35°C. Temperatures outside of this range can cause LIBs to degrade rapidly, leading to increased risks of safety problems, such as fire and explosion.

Temperature impacts can generally be divided into two categories: low temperature effects and high temperature effects. Low temperature effects are mostly observed in high-latitude regions such as Russia, Canada, and Greenland Island. In these areas, outdoor temperatures in winter can drop well below 0°C, which can adversely affect the performance and life of LIBs, particularly in pure electric vehicles (EVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs). Another cold environment where LIBs are used is outer space, where the temperature on planets such as Mars can be as low as -120°C, posing serious challenges to the use of LIBs in astro vehicles for space exploration.

At such low operating temperatures, LIBs exhibit slow chemical-reaction activity and charge-transfer velocity, which can result in a decrease in ionic conductivity in the electrolytes and lithium-ion diffusivity within the electrodes. This decrease can lead to a reduction in energy and power capability and sometimes even performance failure. Therefore, it is critical to find ways to mitigate the impact of temperature on LIBs to enable their continued and expanded use in various applications.

In contrast to the low temperature effects that occur mainly in specific application environments, high temperatureeffects of lithium-ion batteries (LIBs) occur in a wide range of application environments, including both high and low temperature conditions. Unlike low temperature effects, which are mainly attributed to environmental factors, high temperature effects primarily arise from the internal temperature of LIBs during operation. This high internal temperature is generated by heat generated inside the batteries, particularly at high current states, such as fast charging and discharging rates. The detrimental impact of high temperature on battery performance includes a reduction in capacity and power, due to loss of lithium and active materials, and an increase in internal resistance. If the temperature is not controlled properly, it can trigger thermal runaway, which poses a significant safety hazard, including self-ignition and even explosion in some cases.

The temperature effects in LIBs can be attributed to both the chemical reactions occurring within the batteries and the materials used in them. The rate of these chemical reactions is governed by the Arrhenius equation, which establishes a relationship between the rate of chemical reactions and the temperature at which they occur. The electrochemical reaction rate in batteries is affected by temperature variation, making it a crucial factor to consider. In addition to chemical reactions, temperature also affects the ionic conductivities of the electrodes and electrolytes used in the batteries.

1.2.1 Effect of low temperatures

One important factor that contributes to the degradation of LIBs' performance at low temperatures is the increase of charge-transfer resistance. LiFePO4-based cathodes, for example, exhibit a charge-transfer resistance at -20°C that is three times higher than that at room temperature. This high resistance greatly affects the kinetics in batteries. Research demonstrated that the charge-transfer resistance significantly increased as the temperature decreased, and the charge-transfer resistance of a discharged battery is normally much higher than that of a charged one. Charging a battery at low temperatures, therefore, is more difficult than discharging it. In addition to high charge-transfer resistance, low-temperature performance degradation is also associated with the slow diffusion of lithium ions within electrodes. However, this slowdown can be addressed by using electrode materials with low activation energy. For instance, Li3V2(PO4)3 (LVP) has an activation energy of 6.57 kJ/mol and showed a 200x improvement in the apparent chemical diffusion coefficient of lithium ions over LiFePO4 (LFP) with an activation energy of 47.48 kJ/mol at -20°C.

Another typical effect that occurs at low temperatures is lithium plating, which results from the cold condition triggering the polarization of anodes and causing the potential of graphite and other carbon-based anodes to approach that of lithium metal. As a result, lithium-ion intercalation into the anodes during the charging process slows down, and the aggregated lithium ions are deposited on the surface of the electrodes, causing a reduction in battery capacity. Moreover, the lithium plating exists in the form of dendrite, which may penetrate the separators and lead to internal short-circuits.

1.2.2 Effects of High Temperatures

The impacts at elevated temperatures are considerably more intricate compared to those at lower temperatures. As LIBs operate, they produce heat internally, and comprehending the heat generation is crucial in mitigating the adverse effects of high temperatures in LIBs.

1.2.3 Heat Generated

The heat generated within LIBs at normal temperatures is primarily caused by charge transfer and chemical reactions that occur during charging and discharging. The heat can be generated through reversible or irreversible processes in LIBs. Entropic heat, which results from the reversible entropy change during electrochemical reactions, is an example of heat generated in the reversible process. In contrast, many possible irreversible processes can generate heat, including active polarization, ohmic heating, mixing, and enthalpy change. Polarization occurs due to the overpotential between the operating potential and open circuit potential of the batteries, which increases the charge transfer resistance at the electrode-electrolyte interface, also known as the Solid Electrolyte Interface (SEI). When lithium ions overcome this resistance during their intercalation/deintercalation, heat is produced. The ohmic heating process occurs in both the electrode and electrolyte, resulting from the resistance of electrodes and electrolytes that hinders the transportation of charges. The inhomogeneous ion distribution during the operation of LIBs, either during charging or discharging, can lead to ion mixing and heat generation. Finally, another form of irreversible process that generates heat is enthalpy change due to phase changes in cathodes, which is primarily caused by the diffusion of lithium ions.

1.3 Objective of Research

Efficient and reliable battery thermal management systems (BTMS) are essential to ensure optimal performance and long lifespan of electric and hybrid vehicle battery packages. Excessive heat accumulation can lead to thermal runaway, which poses a significant risk to the batteries. The high temperatures generated during charging and discharging of lithium-ion batteries cause temperature nonuniformity and excessive temperature rise within the cells and interconnections. To address this issue, numerous studies have been conducted to develop effective BTMS for EVs and HEVs that can efficiently remove excessive heat from the batteries.

Various cooling methods have been proposed, including air cooling, liquid cooling, phase change material (PCM) cooling, and heat pipe cooling. While PCM-based cooling has demonstrated efficacy, it faces challenges related to low thermal conductivity, extra weight, and leakage. On the other hand, liquid cooling has proven to be the most suitable method for large-scale battery applications in high-temperature environments and at high charging/discharging C-rate. Additionally, different BTMS cooling methods were reviewed and categorized, including refrigerant two-phase cooling and thermoelectric element cooling.

To further improve the performance and safety of Li-ion batteries, the development of BTMS systems should focus on enhancing the thermal management and cooling capabilities of the batteries. Researchers have emphasized the need for battery modeling and thermal management strategies to optimize the design and performance of BTMS systems. A comprehensive review paper focused on liquid-based BTMS systems, with an emphasis on battery modelling and thermal management strategies, could provide valuable insights into the development of efficient and reliable BTMS systems for EVs and HEVs.

CHAPTER 02

LITERATURE REVIEW

CHAPTER 2

Literature Review

Liye Wang [1] performed an analysis, based on the results it is found that the battery thermal management system of water cooling and the cooling effect is good, especially in the 40A charge and discharge is more obvious, and it can reduce the temperature gradient inside of the battery case, the batteries are all working in a stable environment, conducive to maintain consistency of battery pack, and water cooling system need the cooling liquid in the heat dissipated in time to ensure the cooling effect, in actual use, can be installed in the water tank to strengthen fan forced convection on the surface of the box body heat, which can effectively reduce the cooling liquid to reach the purpose of temperature. Cooling plate is provided on the either side of the battery box, with cooling water tubes, that carry away the heat by conduction. The simulation model of cooling plate is established in the pre-processing software Gambit. And by using software fluent for the simulation of transient simulation of cooling plate. The maximum, minimum, mean temperature and standard deviation of temperature are monitored in simulation.

Gang Zhao [2] presented the review study on the air cooling of EV batteries. He conducted an experiment to compare the air, liquid and PCM cooling methods. Based on the results he stated that the applications of novel substructures, such as fins and winglets, would increase the local turbulence and enhance the convective heat transfer within the channels to minimize the hotspots. Furthermore, the combination of state-of-the-art thermally conductive materials, as well as the cooling technologies such as heat pipe and direct evaporative cooling, would further raise the cooling capability of the air-cooling BTMS. To make up the air-cooling capacity, design innovations on new substructures and even conjugated cooling systems combining PCM structures with the air cooling technique can be developed.

The author[3] of the paper aims at describing the various temperature ranges for the lithium ion battery and its effect. The conclusion and results states that the normal operating temperatures for the battery is within 15-35 degree Celsius, for both lower temperature and higher temperature zones and weather, any temperature excluding this range causes deterioration of battery over the period of time and lowers performance. Thus, to control the operating temperature of LIBs and ensure the performance and safety, various battery thermal management systems (BTMSs) are designed for the thermal management of LIBs. For the batteries working under high temperature conditions, the current cooling strategies are mainly based on air cooling , liquid cooling and phase change material (PCM) cooling. Air cooling and liquid cooling, obviously, are to utilize the convection of working fluid to cool the batteries. Out of these, the heat transfer coefficient of liquid is found to be higher than that of air, making it more efficient as the working medium.

This research paper the author [4] provides a review of air-cooling battery thermal management systems (BTMS) for electric and hybrid electric vehicles. The paper discusses the importance of efficient BTMS for optimal performance and long lifespan of vehicle batteries, and the risks of thermal runaway if excessive heat accumulates. The paper focuses specifically on air-cooling BTMS, comparing it to other cooling methods such as liquid cooling and phase change material (PCM) cooling. The authors discuss the advantages and disadvantages of air-cooling systems, including their simplicity, low cost, and low maintenance requirements, as well as their limitations in terms of cooling efficiency and reliability. The paper also discusses various design considerations and optimization techniques for air-cooling BTMS. Overall, the paper provides a comprehensive review of air-cooling BTMS and its potential applications in electric and hybrid electric vehicles.

The research paper [5] focuses on the development of a liquid-cooled battery thermal management system (BTMS) for transient regimes, which are crucial for the optimal performance and safety of electric vehicles. The authors propose a three-dimensional computational model to simulate the thermal behavior of the battery during transient regimes, taking into account the effects of cooling system flow rate and initial battery temperature. The simulation results indicate that a higher flow rate leads to a lower maximum temperature and faster temperature stabilization, highlighting the importance of the BTMS in regulating battery temperature during transient regimes. The study presents a comprehensive analysis of the liquid-cooled BTMS, including the effects of flow rate, initial battery temperature, and heat transfer coefficient. The authors demonstrate the importance of the proposed BTMS in preventing thermal runaway and optimizing battery performance, with implications for the development of electric vehicles and their corresponding thermal management systems.

The paper also discusses the limitations of the study and identifies areas for future research. Specifically, the authors suggest that future studies should investigate the impact of varying design parameters, such as the number and location of cooling channels, on the performance of the BTMS. Additionally, the study highlights the need for further research on the integration of the BTMS with the overall vehicle thermal management system. In conclusion, the research paper provides valuable insights into the development of liquid-cooled BTMS for electric vehicles, emphasizing the importance of efficient and reliable thermal management systems for the optimal performance and safety of batteries in electric vehicles. The paper lays the groundwork for future research in this area and contributes to the ongoing efforts to improve the performance and sustainability of electric vehicles.

The author [6] performsresearch to determine the best possible coolant to be incorporated in the heat pipe for the coolant based cooling system for an EV. Five coolant, viz. Air, water, ethylene glycol, ammonia, R134a are selected and studied based on their specific heat capacity, velocity and flow rate. The conclusion provided by the author, based on numerical and experimental analysis, is that water and ethylene glycol must be used for better cooling of the batteries via contact.

CHAPTER 03

METHODOLOGY

CHAPTER 3

Methodology

This Chapter covers the detail explanation of method that is being used to make this project complete and putting it to the level of generating precise and acceptable results. Here in this chapter we have proposed methods, steps taken at various times for accomplishment of project this include decision making,planning ,calculations and validation.

3.1 Concept of project

In recent times, there have been several incidents of two-wheeler accidents caused by burning. These incidents are believed to be the result of inadequate research and development of lithium-ion batteries. The problem arises from the unpredictable damage that can occur to individual battery cells due to excessive heating when the batteries are under extreme stress. To address this issue, it is necessary to think creatively and develop a thermal management system for the battery pack of electric two-wheelers. Such a system would regulate the temperature of the battery, ensuring that it does not overheat while still providing sufficient power to cool the battery down.

3.2 Research and Collection of Information

Our research focused on identifying real-life challenges associated with the lithium battery of electric vehicles. We conducted a comprehensive analysis of the hardware to gain a thorough understanding of the current limitations in the field. This allowed us to identify specific areas that required further attention and improvement. In addition to studying the hardware, we also examined the power consumption of each system to gain insight into the most effective design parameters for addressing these challenges. We reviewed various research and review papers to ensure that our work was both up-to-date and well-informed. This enabled us to make informed decisions and develop effective solutions for improving the performance and reliability of electric vehicle lithium batteries. Overall, our approach allowed us to take a comprehensive and holistic view of the problem, which proved essential in designing optimal solutions for this complex and multifaceted issue.

3.3 Design of working model

The design of working model and the required material were finalized, all the specifications of components were acknowledged and battery simulator was manufactured in SSGMCE, Shegaon. Further all the sensors and electronic system were studied and designed accordingly. The finished model, then was tested and final results were generated.

3.3.1 Battery simulator assembly

This assembly is made up of mild steel sheet of thickness 5 mm ,It is of dimension 300mm in length and 100mm in width ,but the total used length is 200 mm only and 100 mm length is excess due limitations in the heating rod coil limitations .

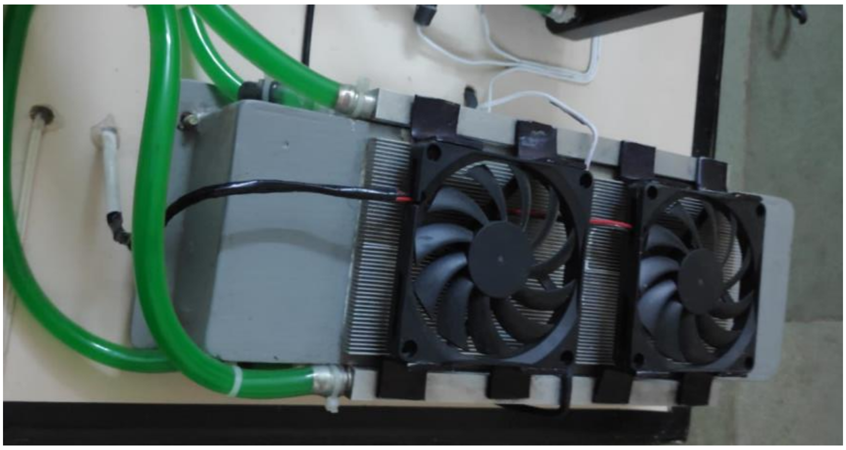


Figure 3.1: Battery Simulator Assembly Used In Project

This battery simulates the precise temperature of 60^{0}C, thus to act as a battery temperature assembly , this temperature range can be set to the precise level, according to various environmental conditions and load conditions .

3.3.2 Room Heater Coil

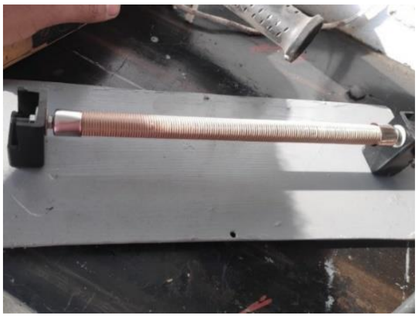


Figure 3.2: Room Heater Coil (1000 W)

The room heater coil is the main heating elements which drives the whole assembly , it is of specifications of 1000Watts , and runs on 240 volts @ 6 amps of current . To set the temperature of this coil we vary the amount of current supplied to it while voltage is kept constant making sure its proper working in variable range of temperature achieved .

3.3.3 Thyristor

It is a Type of regulator which on varying varies the amount of current and , can be set to desired value by the setting of inbuilt potentiometer , this is potential regulator for operating 1000 Watts coil , as this can handle maximum load of 2000 Watts

Figure 3.3: 2000W thyristor

3.3.4 Aluminum Heat Sink assembly

This is having 54 fins of length 8mm, these fins are divided into two parts for ease of assembly each part is of dimension 100mm length wise and 80 mm width wise. All these dimensions are based on the calculated calculations and proven to be optimal for the given temperature range

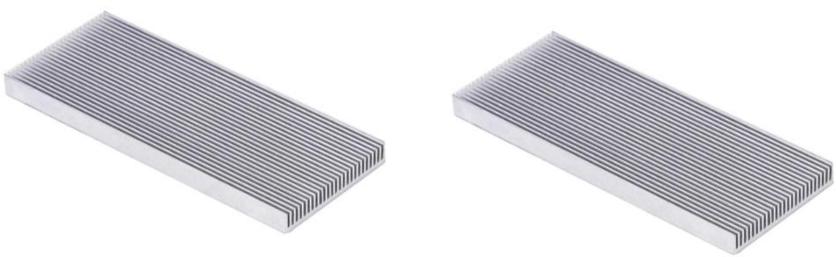


figure 3.4: Aluminum fins

These both fins altogether have dimensions 200 mm length and 80 mm width. Aluminum fins are commonly used in heat sinks to increase their surface area, thereby enhancing their ability to dissipate heat. The working of aluminum fins can be explained in the following steps:

1. Heat transfer: Heat generated by the device being cooled is transferred to the base of the heat sink. The base is typically made of a highly conductive material like aluminum to ensure efficient heat transfer.
2. Heat distribution: The heat is then distributed across the base of the heat sink, and then transferred to the fins. The fins are thin, flat structures that extend from the base of the heat sink, creating a large surface area for heat dissipation.
3. Airflow: Airflow is then directed over the fins using fans or other cooling devices. The air absorbs the heat from the fins and carries it away from the heat sink, dissipating it into the surrounding environment.
4. Heat dissipation: As the air moves over the fins, it removes heat from the fins due to the increased surface area. The heat is then dissipated into the air or other fluid, cooling the device.
5. Repeat: This process of heat transfer, distribution, airflow, and dissipation repeats, allowing for continuous removal of heat from the device.

3.3.5 Water cooling block

An aluminum heat sink block that works on water cooling is designed to dissipate heat generated by a device which generate heat or power electronics component, by transferring the heat from the device to the water flowing through the heat sink block. The working of the heat sink block can be broken down into several steps:

1. Heat generation: The device generates heat as a result of its operation. This heat needs to be removed in order to prevent damage to the device or a decrease in its performance.
2. Heat transfer: The heat generated by the device is transferred to the heat sink block. The heat sink block is made of high thermal conductivity material like aluminum, which ensures efficient heat transfer from the device.

3. Water flow: Water is circulated through the heat sink block by a pump. The water absorbs the heat from the heat sink block as it passes through the channels of the block.
4. Heat dissipation: The water carrying the absorbed heat is then directed to a radiator or other heat exchange device where the heat is dissipated into the air or another fluid.
5. Water return: The cooled water is then returned to the heat sink block and the process repeats, allowing for continuous removal of heat from the device

This water blocks are of dimensions 200mm length and 100 mm width, These are dimensions

Figure 3.5: Aluminum Liquid Cooling Blocks

for one side, this identical set of block is used on either side . these are precisely machined and manufactured of whole aluminum blocks.

3.3.6. Radiator Assembly

A radiator is a heat exchange device that is used to dissipate heat from hot fluids like engine coolant, oil, or transmission fluid, to the surrounding environment. The working of a typical radiator can be broken down into the following steps:

1. Hot fluid enters the radiator: The hot fluid, which needs to be cooled, enters the radiator through an inlet.
2. Cooling fins: The hot fluid flows through a network of small tubes inside the radiator. The tubes are surrounded by thin metal fins that are designed to maximize the surface area available for heat dissipation.
3. Heat transfer to fins: As the hot fluid flows through the tubes, it transfers heat to the surrounding fins. The heat is then conducted from the fins to the air flowing over the fins.
4. Airflow: Air is either drawn through the radiator by a fan or flows over the radiator as the vehicle moves forward. The moving air absorbs the heat from the fins, carrying it away from the radiator and dissipating it into the surrounding environment.
5. Cooled fluid exits the radiator: The now-cooled fluid exits the radiator through an outlet and is directed back to the component it was cooling, such as the engine or transmission.

Figure 3.6: 240 mm radiator used for liquid cooling

The radiator is of length 240 mm and 120 mm width it is specialized for graphics card cooling purpose, it is used along with the cooling fan the working of a radiator involves the transfer of heat from a hot fluid to the surrounding environment through a combination of conduction, convection, and radiation. Radiators are essential components in many applications, including automobiles, power plants, and industrial equipment, where the efficient removal of heat is critical for safe and reliable operation.

3.3.7. Temperature display unit

It is made up of pvc pipe and it has slots accordingly, the temperature sensor units are fitted into it ,these are individual display units these are powered by 1.5 volts individual batteries , and it is just a platform to fix the temperature display

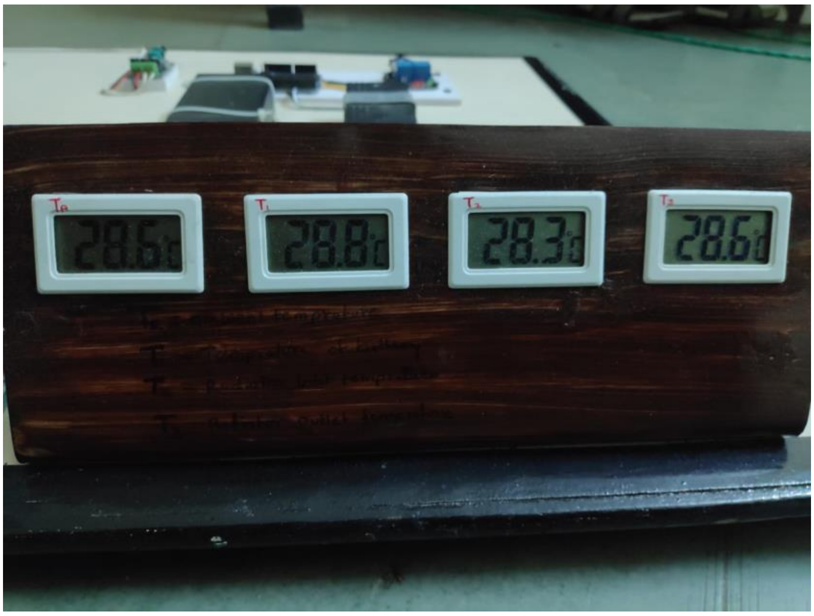


Figure 3.7: Temperature Display Unit

3.3.8. Temperature Sensor DS18B20

The DS18B20 is a digital temperature sensor that is widely used in various applications, including electronics, HVAC systems and industrial control systems. Here are key features and working principles of the DS18B20 temperature sensor.

Figure 3.8: DS18B20 Digital Temperature Sensor

1. Digital output: The DS18B20 temperature sensor provides a digital output, which can be read by a microcontroller or other digital circuitry. The digital output simplifies the interface to the sensor, and makes it easy to integrate with other electronic components.
2. High accuracy: The DS18B20 temperature sensor has a high accuracy of +/- 0.5°C over the range of -10°C to +85°C. This makes it suitable for a wide range of temperature sensing applications where high accuracy is required.
3. One-Wire interface: The DS18B20 temperature sensor uses a One-Wire interface, which means that multiple sensors can be connected to a single data line. This simplifies the wiring and reduces the number of wires needed for the system.
4. Power supply: The DS18B20 temperature sensor is powered by the same data line it uses to communicate with the host system. This eliminates the need for a separate power supply line, further simplifying the wiring.
5. Operating principle: The DS18B20 temperature sensor works by measuring the temperature-dependent resistance of a small silicon-based sensor element. The resistance of this sensor element changes as the temperature changes, and this change is then converted into a digital output by the sensor's internal circuitry.
6. Integration: The DS18B20 temperature sensor can be easily integrated with microcontrollers, using a range of software libraries that are available for popular microcontroller platforms like Arduino, Raspberry Pi, and others. This makes it a popular choice for DIY projects and prototyping.

The DS18B20 temperature sensor is a versatile and reliable digital temperature sensor that offers high accuracy, a One-Wire interface, and easy integration with microcontrollers.

3.3.9. Arduino board

Arduino is an open-source electronics platform that is designed for building electronic projects. The Arduino platform consists of a range of hardware boards, software tools, and a supportive community that allows users to create and experiment with electronics and programming.

Figure 3.9: Arduino Uno Board (Atmega 328P)

Here are some key features and components of an Arduino board:

1. Microcontroller: The heart of an Arduino board is a microcontroller, which is a small chip that can be programmed to control various electronic components like LEDs, sensors, motors, and more.
2. Input/output pins: Arduino boards have a range of digital and analog input/output pins that can be used to connect various sensors, actuators, and other electronic components.
3. Power supply: Arduino boards can be powered by a USB cable or a DC power supply, and can also provide power to external components through the input/output pins.
4. Programming language: Arduino boards are programmed using the Arduino programming language, which is based on the C++ programming language. The language is easy to learn and has a range of libraries and examples that make it easy to get started.
5. Integrated development environment (IDE): The Arduino IDE is a software tool that provides an easy-to-use interface for writing, compiling, and uploading code to the Arduino board.
6. Shields: Arduino boards can be expanded using shields, which are add-on boards that provide additional functionality like Wi-Fi connectivity, motor control, LCD displays and more.

3.3.10. Diaphragm pump 12V

A 12V diaphragm pump is a type of positive displacement pump that is commonly used for transferring liquids and gases in various applications, including agriculture, marine, RV, and automotive industries. The pumps used in project are of capacity of 4 litre per minute each, thus two pumps create the total flow of 8 litre per minute Here is an overview of how a 12V diaphragm pump works:

Figure 3.10: Diaphragm pump 12V

1. Power source: The pump is powered by a 12V DC power source, such as a battery or power supply.
2. Diaphragm: The diaphragm is the main component that moves the fluid or gas through the pump. It is typically made of rubber or other flexible material and is mounted on a plate that moves up and down.
3. Inlet and outlet valves: The pump has two one-way valves, one on the inlet and one on the outlet. These valves allow fluid or gas to flow into the pump on the inlet side and out of the pump on the outlet side.
4. Pumping cycle: When the pump is powered on, the diaphragm moves downward, creating a vacuum on the inlet side of the pump. This vacuum causes the inlet valve to open and fluid or gas is drawn into the pump. As the diaphragm moves upward, it pressurizes the fluid or gas, causing the outlet valve to open and the fluid or gas to be pushed out of the pump.

5. Repeat cycle: The pumping cycle repeats as long as the pump is powered on, with fluid or gas being drawn in on the inlet side and pushed out on the outlet side.

3.3.11 Speed Controller 12V ,2.5 Amp

A 12V, 2.5Amp speed controller is an electronic device used to control the speed of DC motors. It works by varying the voltage and/or current supplied to the motor to adjust its speed. Here's how it works:

Figure 3.11: DC motor speed controller 12V / 24V/ 36V

1. Input power: The speed controller is typically powered by a 12V DC power source, such as a battery or power supply.
2. Control circuit: The speed controller contains a control circuit that adjusts the output voltage and/or current based on the input from the user.
3. Potentiometer: The speed controller is usually equipped with a potentiometer that allows the user to adjust the speed of the motor. The potentiometer is a variable resistor that can be turned to adjust the voltage and/or current supplied to the motor.
4. Pulse width modulation (PWM): Some speed controllers use pulse width modulation (PWM) to control the speed of the motor. PWM works by rapidly turning the power on and off to the motor, with the length of time the power is on (the duty cycle) determining the speed of the motor. The speed controller varies the duty cycle to adjust the motor speed.

5. Transistors: The speed controller contains one or more transistors that act as switches to control the voltage and/or current supplied to the motor. The transistors are turned on and off by the control circuit based on the input from the user.

6. Output power: The speed controller outputs a variable voltage and/or current to the motor based on the input from the user. This variable output controls the speed of the motor.

3.3.12. Relay module 2 Channel

A 2-channel relay module is a type of electronic module that is used to control two different circuits using a single microcontroller or Arduino board. It allows you to use a low voltage signal (such as from a microcontroller) to control a high voltage or high current device, such as a motor, light, or appliance. Here's how it works:

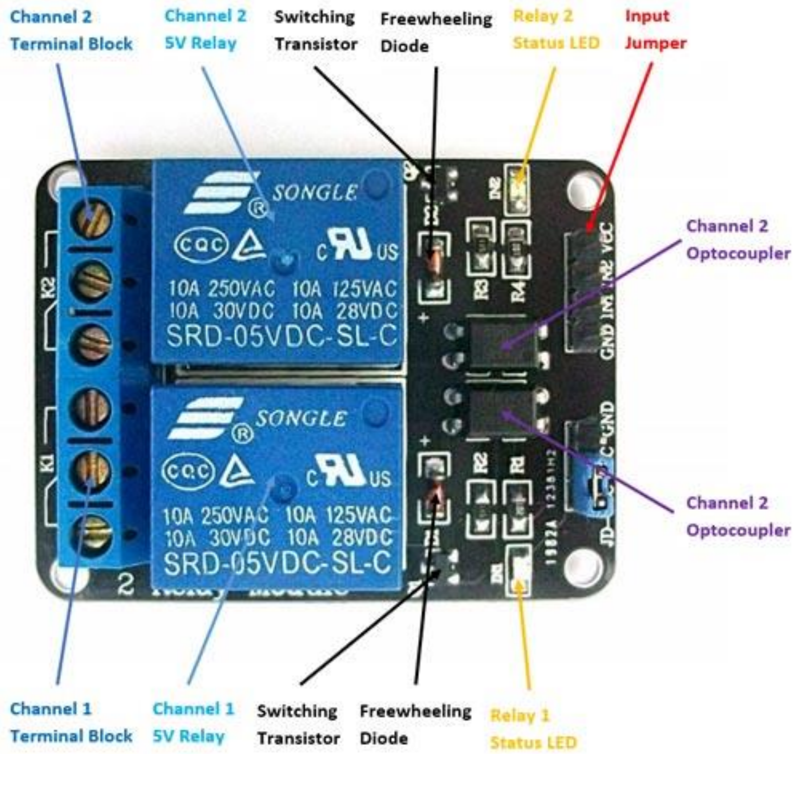


Figure 3.12: Two Channel Relay module

1. Input signal: The relay module is usually controlled by an input signal from a microcontroller, such as an Arduino board. The input signal is typically a digital signal that turns the relay on or off.

2. Relay switches: The module contains two relay switches, each of which can control a separate circuit. A relay is an electromechanical switch that is operated by an electric current. When the input signal from the microcontroller is applied to the relay coil, it creates a magnetic field that pulls the contacts of the relay together or apart, depending on the type of relay.
3. Load circuits: The relay switches are used to control the load circuits, which can be high voltage or high current devices. When the relay is activated by the input signal, it closes the circuit between the power source and the load, allowing the current to flow through the load circuit.
4. Isolation: The relay switches provide isolation between the input signal and the load circuits. This helps to protect the microcontroller from high voltage or high current spikes that may occur when the load circuits are turned on or off.
5. Power source: The relay module requires a power source to operate, which is typically 5V DC. This power source is used to power the relay coils and other circuit components on the module

3.3.13. Brushless DC fan

A brushless DC fan is a type of fan that uses an electronic commutation system instead of brushes and a commutator to control the speed and direction of the fan. Brushless DC fans are more efficient and reliable than traditional brushed DC fans and are commonly used in computer cooling systems, automotive cooling systems, and other applications that require high performance and low noise level

Figure 3.13: Brushless DC Fan 120 mm 12V

A 12V brushless DC fan is designed to operate at a voltage of 12V DC and is typically used in applications that require higher airflow and cooling capacity. Here the air flow is of 110 cubic feet per minutes, such fans are connected to the radiator in this project ,overall 220 cubic feet per minute of air flow is achieved These fans are commonly used in desktop computers, servers, and other electronic devices that require high cooling performance.

A 5V brushless DC fan is designed to operate at a voltage of 5V DC and is typically used in applications that require lower airflow and cooling capacity, such as in mobile devices or small electronics. These fans are also commonly used in Raspberry Pi projects and The fans used in project creates air flow of 10 cubic feet per minute, altogether they create the air flow of 20 CFM .

3.3.14. Coolant reservoir

A coolant tank, also known as a radiator overflow tank or expansion tank, is a component of the cooling system in a vehicle or other machinery that uses a liquid coolant to regulate its operating temperature. The coolant tank serves several important functions:

Figure 3.14: coolant reservoir used in model of project

1. Coolant storage: The coolant tank provides a storage space for excess coolant when the engine is hot and the coolant expands. This prevents the coolant from

overflowing from the radiator and also allows the engine to draw coolant back in when it cools down.

2. Air removal: The coolant tank is typically located at a high point in the cooling system, which allows air bubbles to rise to the top of the coolant and escape into the tank. This prevents air pockets from forming in the cooling system, which can lead to overheating and other issues.
3. Pressure regulation: The coolant tank is designed to maintain a constant pressure in the cooling system by allowing excess pressure to escape into the tank. This helps to prevent the cooling system from becoming over-pressurized, which can cause damage to the system.
4. Coolant level monitoring: Many coolant tanks have a sight glass or other indicator that allows you to monitor the level of the coolant in the system. This can help you identify leaks or other issues before they cause serious problems.

3.3.15. Coolant

Coolant, also known as antifreeze, is a liquid used in an automobile's cooling system to regulate the engine's operating temperature. It circulates through the engine and absorbs heat generated by the combustion process, transferring it to the radiator where it is dissipated.

The primary function of coolant is to prevent the engine from overheating. It also prevents the formation of rust and corrosion in the engine's metal components, which can cause leaks and other issues over time. In addition, coolant helps to prevent freezing in cold temperatures, which can cause damage to the engine block and other components.

Figure 3.15: BOSCH Auto-cool coolant

Most modern automobiles use a mixture of water and ethylene glycol-based coolant, with a typical mixture ratio of 50/50. This mixture provides good heat transfer properties, corrosion protection, and freezing point depression.

3.3.16. Coolant Tubes

These tubes are designed to withstand high pressure and temperature ranges, as well as exposure to various chemicals and environmental conditions. Coolant hoses are used to transport engine coolant from the radiator to the engine and back. These tubes are typically made of high-pressure rubber and are designed to withstand high temperature and exposure to engine coolant. We have used normal 8mm diameter tubes for cost effectiveness, as we do not have to deal with much higher temperatures.

3.3.17. Power supply 12V ,3A

A 12V, 3A power supply is a device that provides a constant voltage output of 12 volts DC (Direct Current) and a maximum current output of 3 amps. This type of power supply is commonly used to power electronic devices, such as routers, modems, and LED lighting systems, that require a stable and reliable source of power.

The power supply typically consists of a transformer, a rectifier, and a smoothing capacitor, which work together to convert the incoming AC (Alternating Current) voltage from the mains power supply to the desired output voltage and current.

Figure 3.16: SMPS Adaptor 12Volts , 3Ampere

The transformer is responsible for stepping down the incoming AC voltage to a lower voltage suitable for the rectification process. The rectifier then converts the AC voltage to a DC voltage, which is further smoothed out by the capacitor to provide a stable output voltage.

The power supply may also include protection circuitry, such as over-voltage protection, over-current protection, and short-circuit protection, to prevent damage to the device being powered in case of any faults or failures in the power supply.

In order to use a 12V, 3A power supply, the device being powered must have the correct input voltage and current requirements.

3.3.18. Power supply 5V, 4 Amp

A 5V, 4A power supply is a type of Switched-Mode Power Supply (SMPS) that provides a constant voltage output of 5 volts DC (Direct Current) and a maximum current output of 4 amps. SMPS power supplies are commonly used in a variety of electronic devices, such as smartphones, tablets, and computers, due to their efficiency and compact size.

The SMPS power supply uses a switching regulator to convert the incoming AC (Alternating Current) voltage from the mains power supply to the desired output voltage and current. The switching regulator consists of several key components, including a high-frequency oscillator, a rectifier, a filter, and a voltage regulator.

Figure 3.17: SMPS Adaptor 5 Volts , 3Ampere

The high-frequency oscillator generates a high-frequency signal that is fed into the rectifier, which converts the incoming AC voltage to a DC voltage. The DC voltage is then filtered to remove any unwanted noise or fluctuations, and the voltage regulator adjusts the voltage to the desired level of 5 Volts.

The SMPS power supply may also include protection circuitry, such as over-voltage protection, over-current protection, and short-circuit protection, to prevent damage to the device being powered in case of any faults or failures in the power supply.

In order to use a 5V, 4A power supply, the device being powered must have thecorrect input voltage and current requirements. It is important to ensure that the polarity of the power supply matches the device being powered, as well as the correct plug size and connector type.

3.4 Working Procedure

1. This project is about thermal management of an electric vehicle's battery, so we aim to keep the battery in desired temperature range. To do this we use air cooling as well as liquid cooling air cooling is called as convection and liquid carries heat by direct contact which is called conduction.
2. Liquid cooling is most effective but consumes more amount of current making it a bad choice to keep it always on as this would result in loss of range of an electric vehicle and thus putting an extra load on battery.
3. Unlike liquid Cooling air cooling is more energy saving method but it is less effective on higher temperatures, above 45^0C it does not provide Desirable results, therefore we choose to switch between these two systems by using Arduino logic board and DS18B20 temperature sensor , So that natural convection within range of 40^0C was used , above 40^0C and up to 45^0C forced convection is used.
4. When temperature goes above 45^0C up to 55^0C liquid cooling is used, and above 55^0C which is danger temperature limit for lithium battery ,both systems were used this combination of systems is named as hybrid cooling.

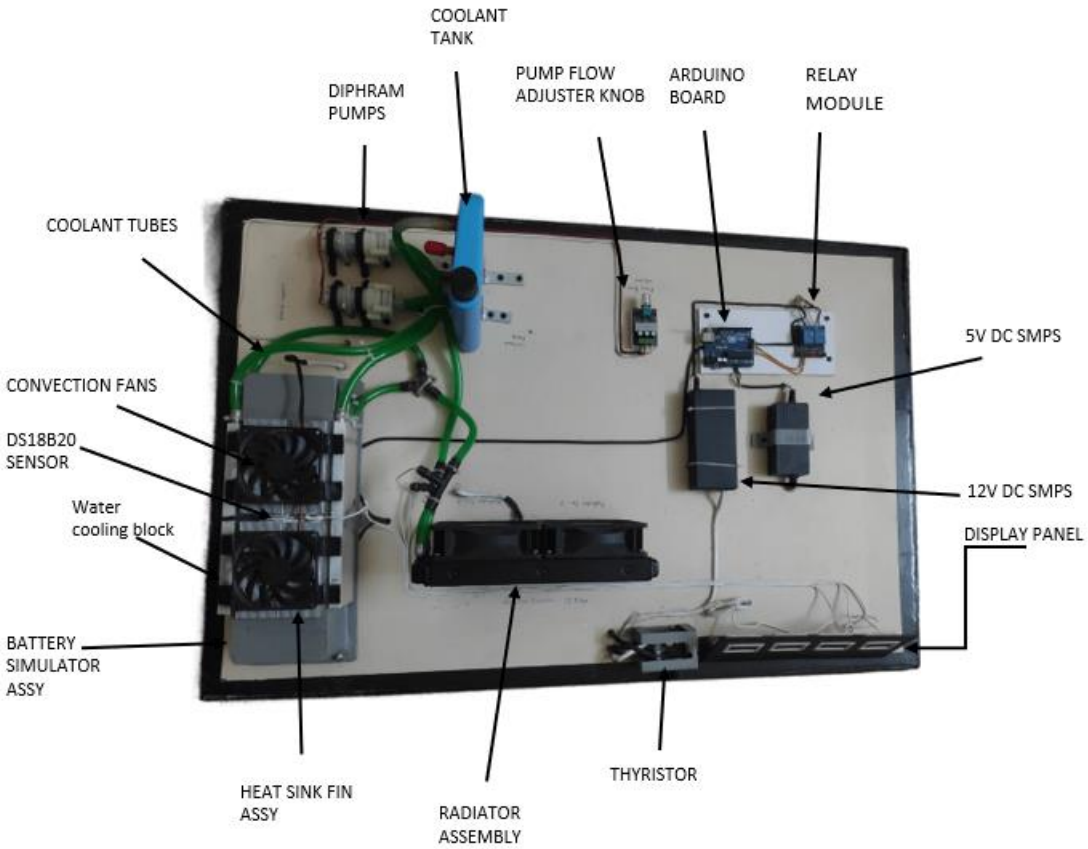


Figure 3.18: Actual Photo Of Working Model

3.5 Procedure of operation

1. Turn on the project by plugging the plug in power socket and switching on power supply. (make sure that power supply is reliable as load connected is of 1000Watts/240V).
2. This will result in heating of battery simulator, now set knob of thyristor to 60^0C.
3. Make sure other knob present in project is for pump flow control, this should be kept off, so that battery will reach to the desired temperature level.
4. Now noticeable raise in battery's temperature can be observed.
5. Attach data wire to Arduino and other end to computer, open serial monitor by going to project code and clicking the icon present in upper right corner.
6. Now precise real time readings of temperature of battery form DS18B20 sensor are available .
7. Also note down T_A , T_1 ,T_2 ,T_3 . these are ambient temperature ,battery temperature , radiator inlet temperature and radiator outlet temperature.
8. Note that temperature display do not show always precise temperature reading and its survey cycle is for 10 sec . also its range of accuracy varies from $+1^0$C to -1^0C form real temperature .
9. As temperature goes up different system start operating on feedback received from sensor .
10. As temperature goes above 45^0C , make sure to turn on pump flow knob to the maximum position
11. Note down the temperature drop while natural convection , forced convection , conduction as well as convection along with conduction is occurring.

3.6 Code For Arduino

//Arduino used for switching into the cooling systems

// Optimised for Arduino UNO,NANO _ temperature sensor DS18B20 _ and two channel relay module has been used to operate between air cooling and liquid cooling.

```
#include <OneWire.h>

#include <DallasTemperature.h> // This library is for Ds18b20 temperature sensor ,we have downloaded from github .


#define ONE_WIRE_BUS 8


OneWireoneWire(ONE_WIRE_BUS);


DallasTemperature sensors(&oneWire);


float Celsius = 0;        // These are the float integers and can be allocated different temperature values

float Fahrenheit = 0;     // These are the float integers and can be allocated different temperature values


void setup() {

sensors.begin();

Serial.begin(9600);// this is the Baud rate at which our sensors work and we must select the same while opening serial monitor .

pinMode(6,OUTPUT);// connect fans here 5v dc

pinMode(7,OUTPUT);// connect motor and radiator fans here

pinMode(5,OUTPUT);// connect buzzer here

}


void loop() {

sensors.requestTemperatures();  //here library is used ,and to get the temperatures we written the code from library
```

```
  Celsius = sensors.getTempCByIndex(0);

  Fahrenheit = sensors.toFahrenheit(Celsius);


Serial.print(Celsius);        // these commands are for serial monitor and ,the same
ahall be displayed on the serial monitor

Serial.print(" C  ");

Serial.print(Fahrenheit);

Serial.println(" F");


delay(1000);

if((Celsius>40)&&(Celsius<=45))// to operate the 5v dc fans when temperature goes
above 40 dc to the 45 degrees .

  {

digitalWrite(6,LOW);

digitalWrite(7,HIGH);

                        // Here we havent set delay as we are operating between two defined
temperature conditions .

  }

  else if ((Celsius>45)&&(Celsius<=55))//To operate the radiator fans  and pumps for
water cooling ,when temperature goes above 45degrees and up to 54 degrees .

   {

digitalWrite(7,LOW);

digitalWrite(6,HIGH);

    }

                      // Here we have not set delay as we are operating between two defined
temperature conditions .

  else if((Celsius>55.0))// To operate both the devices when temperature goes above
55℃ we operate both the pumps.

    {

digitalWrite(7,LOW);

digitalWrite(6,LOW);

    }
```

```
   else
  {
digitalWrite(7,HIGH);//  to make sure all the system is in off position
digitalWrite(6,HIGH); //  to make sure all the system is in off position

  }
delay(100);

}
```

CHAPTER 04

CAD MODEL

CHAPTER 4

CAD Simulation of the Battery with Fins and Water Jackets

4.1 Modelling of Battery

The battery is designed in such a way that it can similar to how the final battery is made for experiment analysis. So, to create this battery the dimension are taken as 200mm×75mm×100mm this dimension are taken because most of the batteries used for the Electric two wheelers are of this specification. Also, the internal portion of the battery is taken as hollow. To create this hollow part 'Shell command' is used in 'Create Tab' and a 5mm thickness shell is of battery is created.

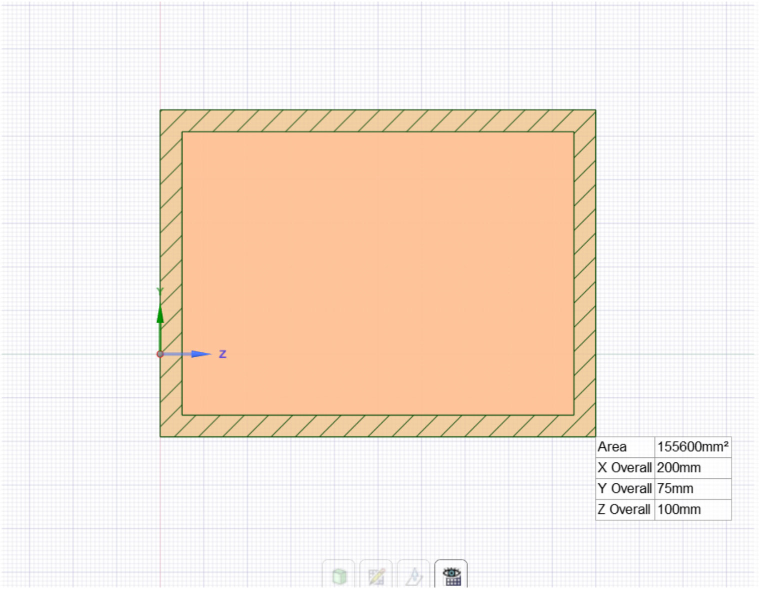


Figure 4.1: Cross-section view of the Battery

4.2 Modelling of Fins

Designing fins in ANSYS SpaceClaim involves creating a 3D model of the fin geometry and performing simulations to analyze its thermal performance. Certain calculations are required for the Designing of fins that are as follows.

1. Heat transfer calculations: Fins are designed to dissipate heat, so it is important to calculate the heat transfer coefficient of the fin and the surrounding fluid. This involves analysing the flow of heat through the fin and the convective heat transfer from the fin surface to the surrounding fluid.

2. Fluid flow calculations: The performance of the fin is also affected by the flow of fluid around it. Calculations are required to determine the fluid velocity, pressure, and temperature around the fin, as well as the effect of turbulence and other flow characteristics.
3. Fin dimensions and spacing: The design of the fin involves determining the appropriate dimensions, such as length, thickness, and spacing, to optimize its surface area and heat dissipation performance.

After the calculations and simulation which is performed further in this Chapter, it was found out that 54 number of fins is optimal for Heat dissipation.

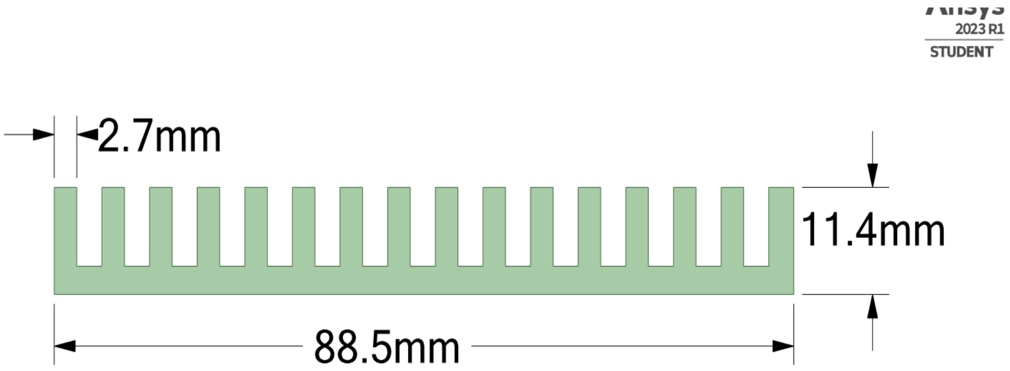


Figure 4.2: Battery with 16 Fins

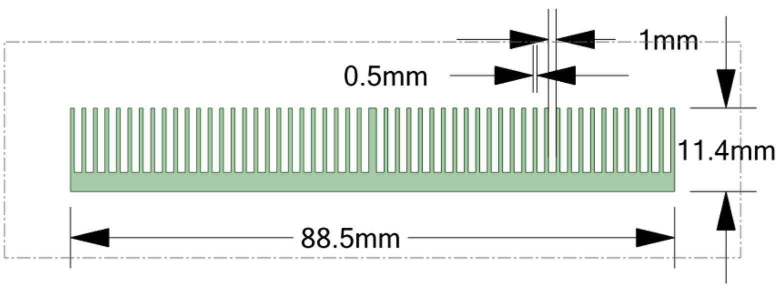


Figure 4.3: Battery with 54 fins

4.3 Modelling of Water-Cooling Blocks

An aluminium heat sink block that works on water cooling is designed to dissipate heat generated by a device which generate heat or power electronics component, by transferring the heat from the device to the water flowing through the heat sink block. The dimensions for the modelling of the Water-cooling blocks are taken directly for the specification sheet of the part that are used in Final model.

The grey part in the tubes represents the volume of water flowing through the water-jackets.

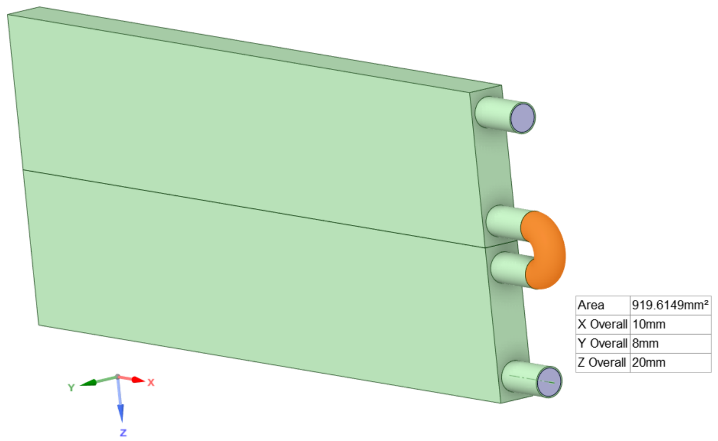


Figure 4.4: Final Model of the Water-cooling

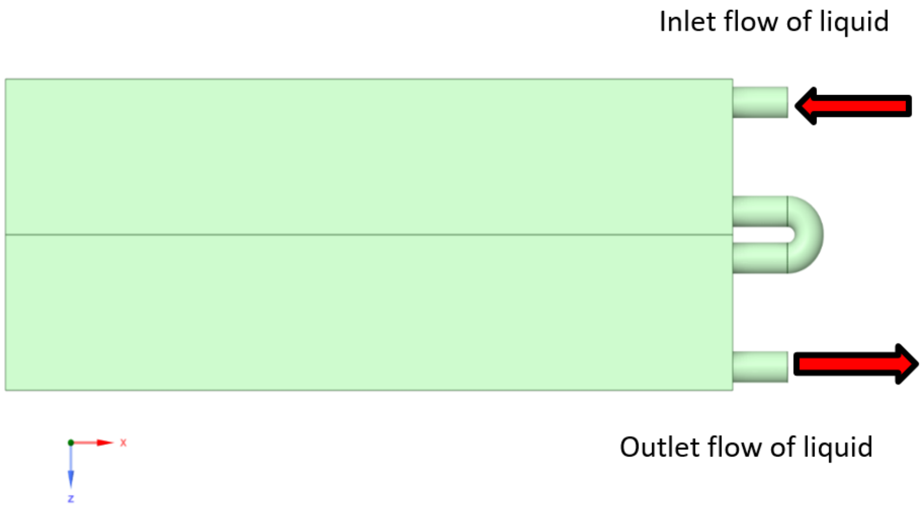


Figure 4.5: The inlet and outlet of the Water-Jacket

4.4 Final Assembly

For the final model all the above individual parts are assembled in one final model i.e. Battery is in center and on both side of it is the water jacket block and on top of the battery fins are situated. This is done with the help of 'Assembly' option in the Ribbon in the SpaceClaim. All the parts are imported one by one and various constraint are applied to get the final model of dimension 225.014 mm×120 mm×85.9 mm.

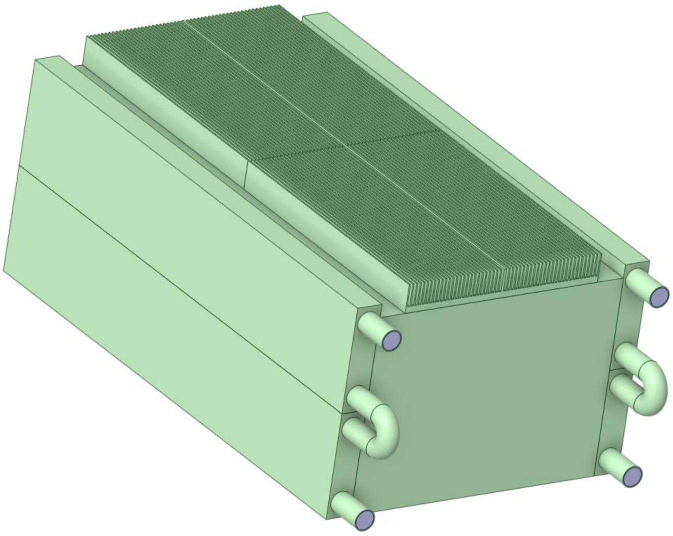


Figure 4.6: Final assembly ready for simulation

CHAPTER 05

ANALYSIS OF COOLING SYSTEM

CHAPTER 5

Analysis of Cooling System byANSYS workbench 2023 R1

5.1 Theme of Computer Simulation

Thermal analysis of fins is important because fins are commonly used in various engineering applications to enhance heat transfer between a solid surface and the surrounding fluid. The purpose of a fin is to increase the surface area of a solid object, which can then be used to dissipate heat more efficiently. The effectiveness of the fins in enhancing heat transfer depends on various factors such as the shape and size of the fins, material properties, and the fluid flow rate.By performing thermal analysis of fins, engineers can optimize the design of fins to achieve better heat transfer performance. Also, the temperature drop in different cases by simulation can be further compared with experimental analysis results.

- Selection of proper fins for the model
- Results of the different cooling method

5.2Material Selection for Computer Simulation

Material selection is an important consideration in ANSYS because the behavior of a structure or system is greatly influenced by the properties of the materials used to construct it. In steady-state thermal analysis because it directly affects the heat transfer properties of the system being analyzed. Different materials have different thermal conductivities, specific heat capacities, and other thermal properties that affect how they transfer heat.

Sr. No	Name of the materials	Thermal Conductivity (W/m°C)
1	Aluminium	237
2	Structural Steel	60.5
3	Water Liquid	0.6
4	Air	0.0258

Table5.1: Thermal properties of materials used in computer simulation

Fins and Water-Jacket areused in this project are made of aluminium instead of copper due to several factors including thermal conductivity, cost, and weight.While copper has a higher thermal conductivity than aluminium, it is also significantly more expensive and heavier than aluminium. Therefore, aluminium fins are often preferred for their lower cost and lighter weight.

As seen in the table 7.1the Air and water properties are when they are in ideal conditions.

5.2.1 Design of Parts for Computer Simulation

For designing of parts Ansys SpaceClaim is used because Designing in ANSYS SpaceClaim has several benefits that make it a popular choice for engineers and designers. These benefits include a user-friendly interface, quick and efficient geometry creation, direct modelling capabilities, integration with ANSYS simulation tools, and multi-CAD compatibility. Its direct modelling capabilities allow for easy creation and modification of geometry without worrying about feature histories or dependencies, while its integration with ANSYS simulation tools makes it easy to create geometry for simulations and transfer data seamlessly between the two programs. ANSYS Space Claim's multi-CAD compatibility also allows users to import and export geometry in a variety of CAD formats, making it easy to work with designs from multiple sources.

This chapter includes an in-depth numerical examination of the battery's fins and three alternative boundary conditions. The temperature drop is seen in the result of the first simulation, which compares the use of 16 and 54 fins. The other simulation involves cooling the battery using heat in three different scenarios. 1) Air cooling alone is employed. 2) Liquid cooling alone is employed 3. The utilization of hybrid cooling. For a more reliable, consistent outcome, the ambient temperature for every simulation is assumed to be 32°C. Additionally, it is assumed that the battery temperature is 60°C under ideal circumstances. Additionally, it is assumed that the battery temperature is 60°C under ideal circumstances. Ansys 2023R1 is the program being used in this instance, and it includes Steady State Thermal. A computer simulation program called ANSYS Steady-State Thermal offers precise examination of steady-state thermal activity. Finite element analysis is used to manage complicated geometries, material characteristics, and a variety of boundary conditions, including convection, radiation, and conduction. Iterative design processes and the ability to examine the effects of various design decisions on thermal performance are all made possible by the time and money-saving thermal analysis tool known as ANSYS Steady-State Thermal. Engineers and designers across various sectors value it for its extensive capabilities.

5.3 Meshing of Components

After the modelling of the fins and battery, the next step is the meshing of the components. Meshing is a crucial step in ANSYS simulations as it involves dividing the model geometry into smaller, finite elements to allow for more accurate analysis. The quality and accuracy of the mesh can have a impact on the simulation results.

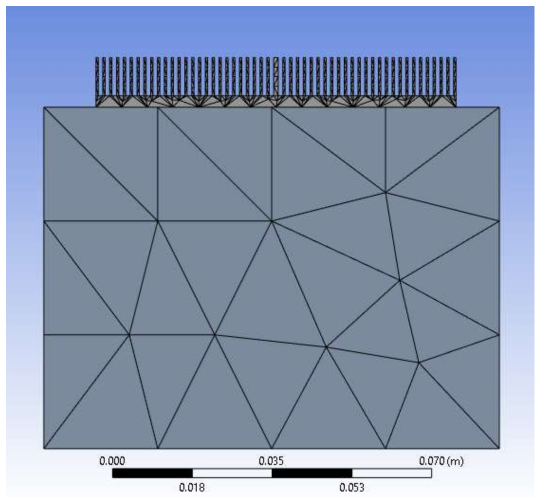


Figure 5.1: Meshing of battery with fins

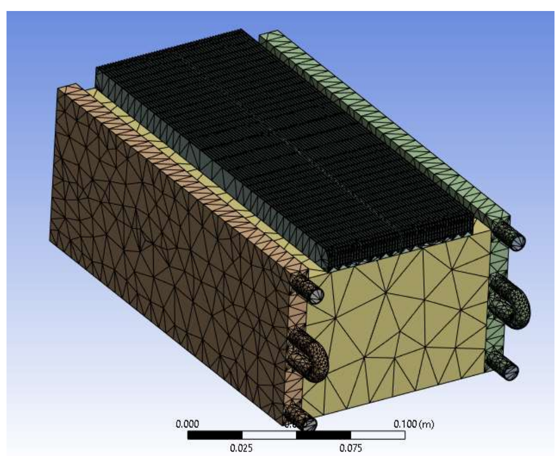


Figure 5.2: Meshing of Battery with fins and water

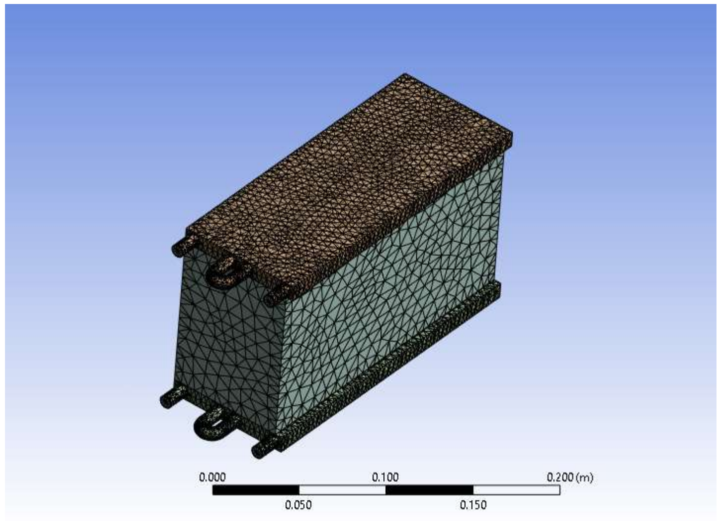


Figure5.3: Meshing of Battery with water block

5.4 Boundary Conditions

1. Battery with only fins: In this case the boundary conditions were considered as follow

- Ambient Temperature: As the atmospheric temperature while doing this simulation and experimental analysis was around 32℃, we have taken initial temperature as 32℃ for every simulation for consistency.
- Internal Heat Generation: The Heat generation takes place form inside the battery to the outside. To simulate this type of situation this Boundary condition is used. Its values is taken as 12000 W/m^2, this is derived form simple calculation and the surface temperature of battery with no fins produces 60℃ at this same value.
- Convection: For convection we have to use it multiple times, there are two convection taking place in this simulation one is between the ambient atmosphere and battery surface and second is fins with ambient atmosphere. This is because the value of film coefficient for the convection of fins with air will be slightly more compared to the surfaces with no fins with air. Here, the film coefficient factor is considered as 2.6 W/m^2 × ℃ for the face which are coming with contact with air and 4.2 W/m^2 × ℃ for the fin's interaction with ambient air.

2. Battery with only Water Jackets: In this case the boundary conditions are almost same but the fins are not present so the film coefficient is calculated for Water-Blocks. The heat generation operation will be same for all the three cases.

- Ambient Temperature: As the atmospheric temperature while doing this simulation and experimental analysis was around 32℃, we have taken initial temperature as 32℃ for every simulation for consistency.
- Internal Heat Generation: The Heat generation takes place form inside the battery to the outside. To simulate this type of situation this Boundary condition is used. Its values are taken as 12000 W/m^2, this is derived form simple calculation and the surface temperature of battery with no fins produces 60℃ at this same value.
- Convection: The convection taking place here are of two different types, one is between the surface of battery and ambient air and second is for the liquid inside the water block and the surface of the battery. It is obvious that the liquid will have more film coefficient as compared to the air. For this simulation the Film coefficient is 16 W/$m^2 \times$ ℃. The value of the film coefficient for the battery free surface and air is 2.6 W/$m^2 \times$ ℃ which is common as previous case.

3. Battery with both Air-cooling and Water-jackets: for this case the boundary conditions of both the previous cases are used. The most significant change is that, in this there are 3 values of film coefficient for three convections.

- Ambient Temperature: As the atmospheric temperature while doing this simulation and experimental analysis was around 32℃, we have taken initial temperature as 32℃ for every simulation for consistency.
- Internal Heat Generation: The Heat generation takes place form inside the battery to the outside. To simulate this type of situation this Boundary condition is used. Its values are taken as 12000 W/m^2, this is derived form simple calculation and the surface temperature of battery with no fins produces 60℃ at this same value.
- Convection: The convection taking place here are of two different types, one is between the surface of battery and ambient air and second is for the liquid inside the water block and the surface of the battery. It is obvious that the

liquid will have more film coefficient as compared to the air. For this simulation the Film coefficient is 16 W/m^2 × ℃. The value of the film coefficient for the battery free surface and air is 2.6 W/m^2 × ℃ which is common as previous case. And with this we also used fins in the case so we have to consider the fin so, the third film coefficient's value is 4.2 W/m^2 × ℃.

5.5 Results

- From the simulation it was clear that the fins are only able to drop the battery temperature up to the range 43 - 45℃. After this the values did not change, below is the result form the simulation.

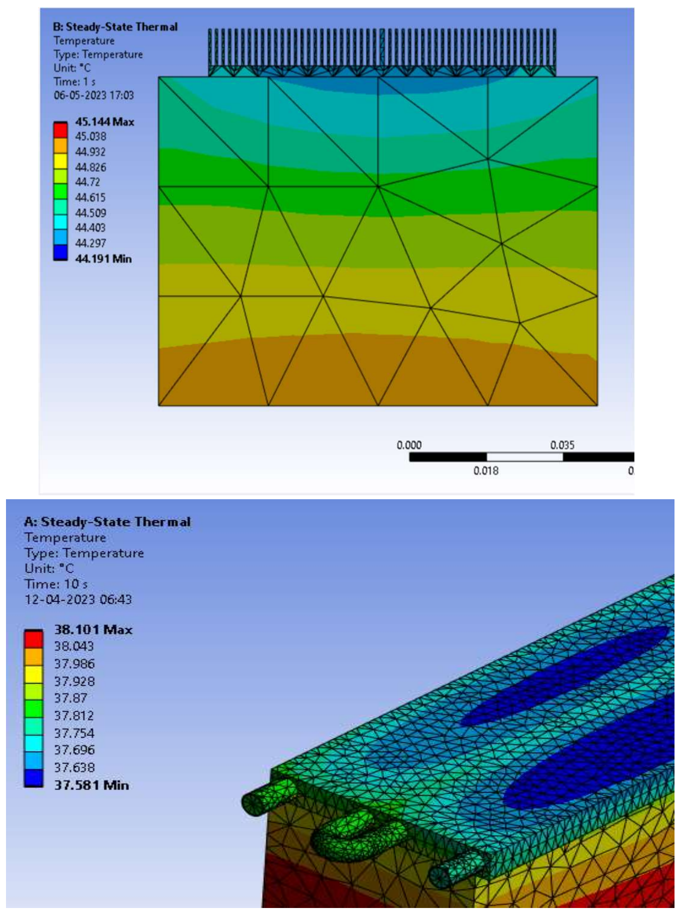


Figure5.4: Battery with Air cooling

- For the Liquid cooling the temperature drop is more because liquid cooling is generally considered more effective than air cooling because liquids have a higher thermal conductivity and heat capacity than air. This means that liquids are better at absorbing and dissipating heat compared to air. Additionally, liquids can be circulated through a cooling system, allowing for more targeted and efficient cooling of specific components. Here the temperature drop is 7 ℃ more compared to air cooling. Below is the simulation result for the Battery with liquid cooling.

- It is observed in third case that by using the hybrid cooling which uses both the liquid cooling and the air cooling the temperature of the battery falls to that of ambient temperature with the battery still at the same heat generation rate as for the other cases. The temperature drop between hybrid and only liquid cooling is 4 ℃. Below show the actual simulation results.

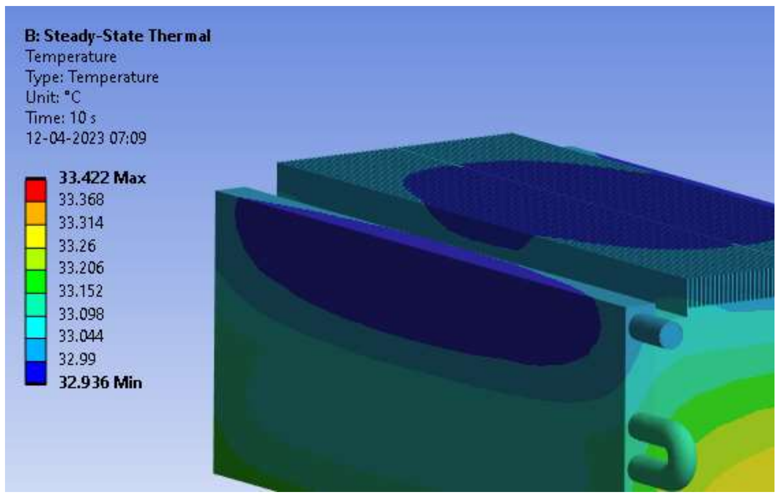
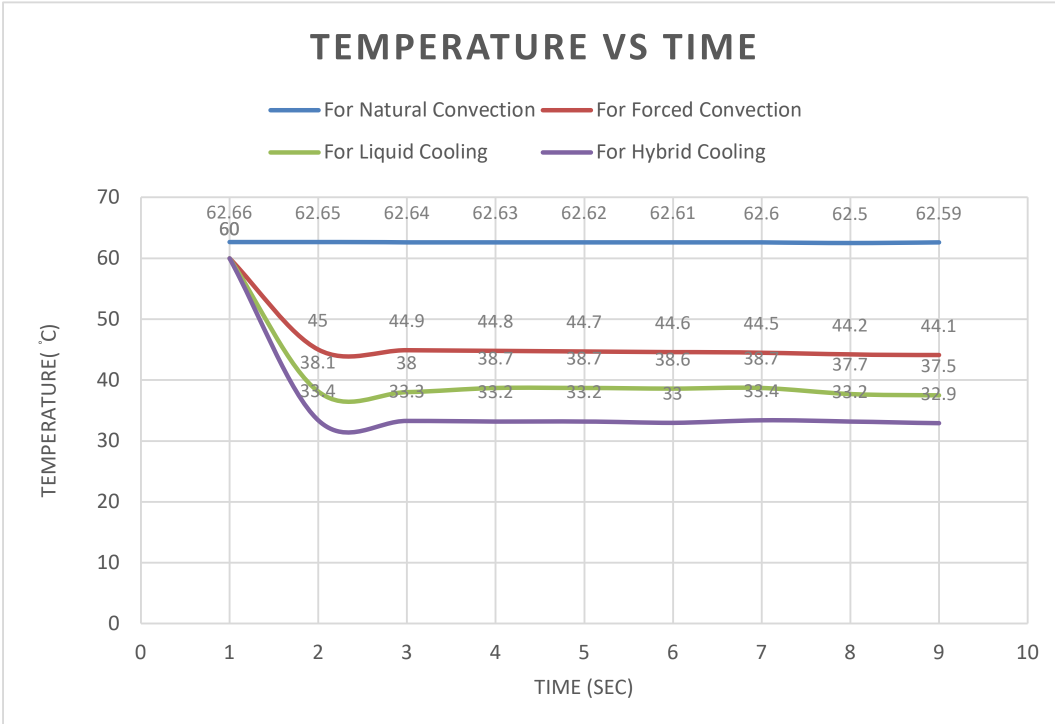


Figure5.5: Battery with hybrid cooling

- A graph can be plotted with above data and we have seen above the heat dissipation in each case.



CHAPTER 06

RESULT AND DISCUSSIONS

CHAPTER 6

Result and Discussion

The following are the observations for the proposed cooling system

Type Of Cooling	Temperature Of Battery in degree Celsius	Time In Seconds
Natural cooling T_A =ambient temp, 30.6°c	60.3	00
	60.2	300
	60.2	600
	60.1	900
	60.1	1200
	60.1	1500
	60.1	1800
	60.0	2100
	60.0	2400
	60.0	2700
	59.9	3000
	59.9	3300
	59.9	3600
Air Cooling (Forced Convection By Fins On Top Face) T_A =ambient temp, 30.6°c	60.2	00
	56.9	60
	54.5	120
	52.9	180
	51.9	240
	51.2	300
	50.8	360
	50.6	420
	50.3	480
	50.1	540
	49.8	600
	49.6	660
	49.3	720
	49.0	780
	48.7	840
	48.6	900
	48.6	960
	48.6	1020
Liquid Cooling (conduction) T_A =ambient temp, 32.2°c	60	00
	57.2	60
	53.8	120
	51.9	180
	49.5	240
	47.8	300
	46.6	360
	45.7	420
	44.9	480
	44.3	540
	43.8	600
	43.4	660
	43.1	720
	42.6	780
	42.6	840
	41.8	900
	41.4	960
	41.1	1020
	40.9	1080
	40.8	1140
	40.8	1200
Hybrid Cooling (air + liquid cooling) T_A =ambient temp, 32.8°c	60	00
	58.6	60
	52.2	120
	48.3	180
	45.0	240
	42.3	300
	40.8	360
	39.4	420
	38.3	480
	37.1	540
	36.2	600
	35.5	660
	34.9	720
	34.3	780
	33.9	840
	33.5	900
	33.2	960
	33.0	1020
	32.9	1080
	32.8	1140
	32.8	1200
	32.8	1260

Table 6.1:Observations

6.1. Natural Cooling

- The ambient temperature was 30.6 ^{0}C, the battery was heated to 60.3^{0}C stable temperature state and left for cooling without any turbulence of air ,naturally it cooled down to 59.9 ^{0}C over the span of 1 hour .
- This means our battery has dropped the temperature of 0.4^{0}C in span of 1 hour when it is cooled by natural convection.
- This method has proven to be least effective method for cooling the battery.

6.2. Air Cooling

- The ambient temperature was 30.6^{0}C , the battery was heated to 60.2^{0}C stable temperature state and left for cooling with 20 cubic feet per minute @ 10meter/second of air flow turbulence of air ,it cooled down to 48.6^{0}C over the span of 17 min , after that temperature got stable and was not getting lowered.
- This means our battery has dropped the temperature of 11.6^{0}C in span of 17 minutes when it is cooled by forced convection.

- This method is proven to be more effective than natural cooling ,but less effective than Liquid cooling

6.3. Liquid Cooling

- The ambient temperature was 32.2^0C , the battery was heated to $60.^0$C stable temperature state and left for cooling with conduction by liquid cooling it cooled down to 40.8^0C over the span of 20 min , after that temperature got stable and was not getting lowered.
- This means our battery has dropped the temperature of 19.2^0C in span of 20 minutes when it is cooled by conduction.
- This method is proven to be more effective than forced convection ,but less effective than Hybrid cooling.

6.4. Hybrid Cooling

- The ambient temperature was 32.8^0C , the battery was heated to $60.^0$C stable temperature state and left for cooling with conduction by liquid cooling and convection by air cooling it cooled down to 32.8^0C over the span of 21 min , which was our ambient temperature.
- This means our battery has dropped the temperature of 27.2^0C in span of 21 minutes when it is cooled by Hybrid Cooling.
- This Method is proven to be most effective in the terms of cooling on performing experiment.

6.5 Simulation Results

- From the simulation it was clear that the fins are only able to drop the battery temperature up to the range 43 - 45°C. After this the values did not change, below is the result form the simulation.

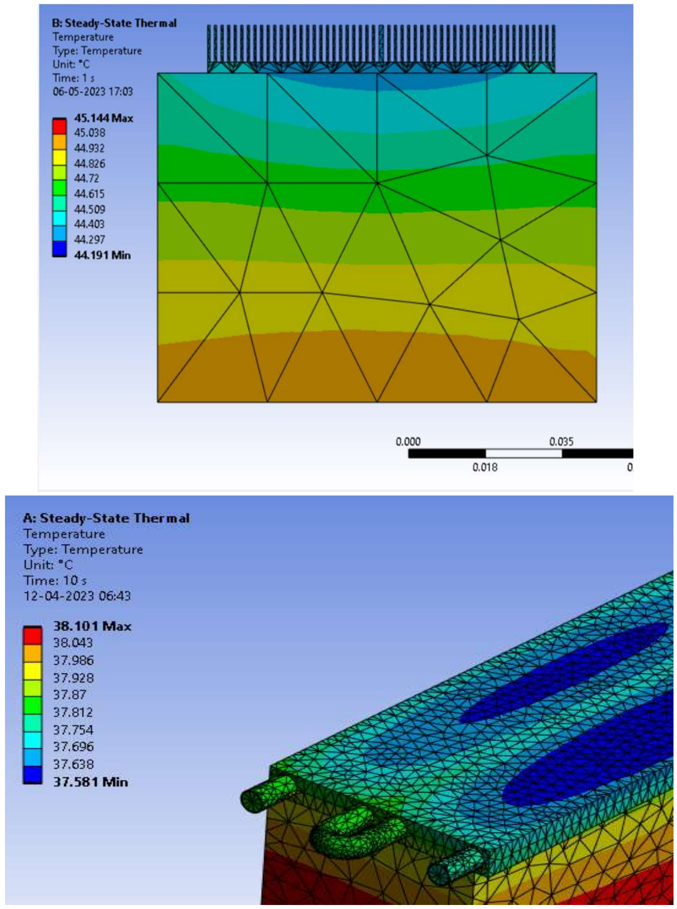


Figure 6.1: Battery with Air cooling

- For the Liquid cooling the temperature drop is more because liquid cooling is generally considered more effective than air cooling because liquids have a higher thermal conductivity and heat capacity than air. This means that liquids are better at absorbing and dissipating heat compared to air. Additionally, liquids can be circulated through a cooling system, allowing for more targeted and efficient cooling of specific components. Here the temperature drop is 7 °C more compared to air cooling. Below is the simulation result for the Battery with liquid cooling.

- It is observed in third case that by using the hybrid cooling which uses both the liquid cooling and the air cooling the temperature of the battery falls to that of ambient temperature with the battery still at the same heat generation rate as for the other cases. The temperature drop between hybrid and only liquid cooling is 4 °C. Below show the actual simulation results.

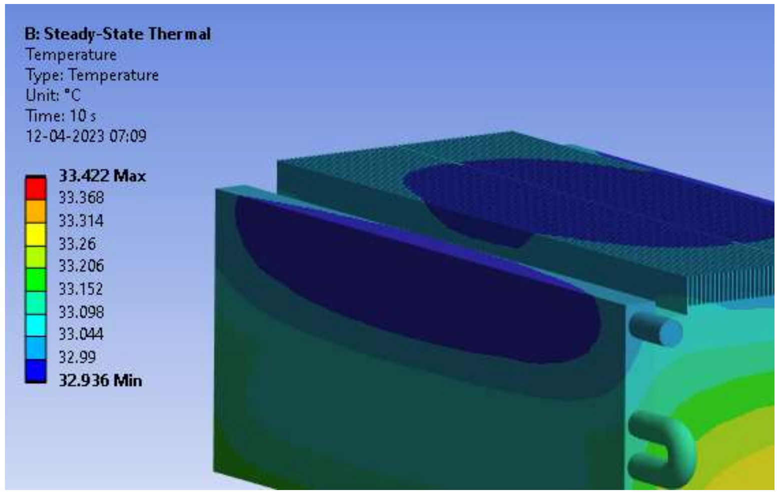
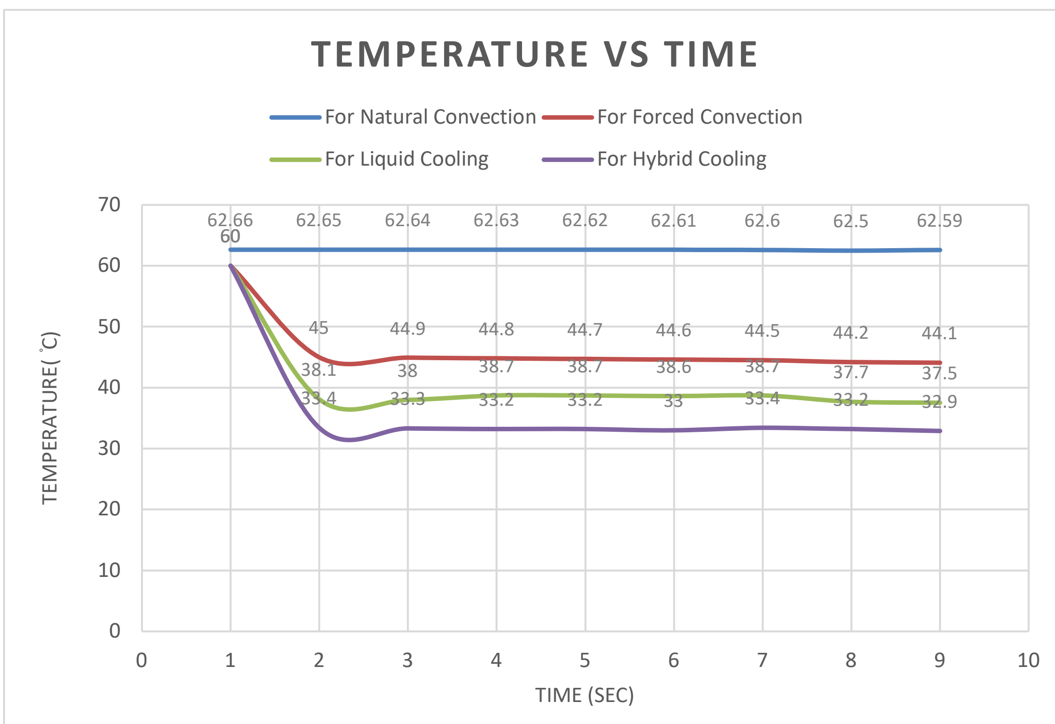


Figure 6.2: Battery with hybrid cooling

- A graph can seen above the heat dissipation in each case.



- The thermal research revealed that the use of fins causes a temperature drop of 10 degrees Celsius due to air cooling under typical operating conditions. However, under extreme discharging circumstances, the temperature reduction produced by fins alone could not be adequate and could still harm the batteries.
- In order to resolve this problem, it was discovered that switching between air and liquid cooling systems according to the needs allows them to be combined more effectively. While forced convection can be cooled with air, which is more energy-efficient, severe conditions can be cooled using liquid.

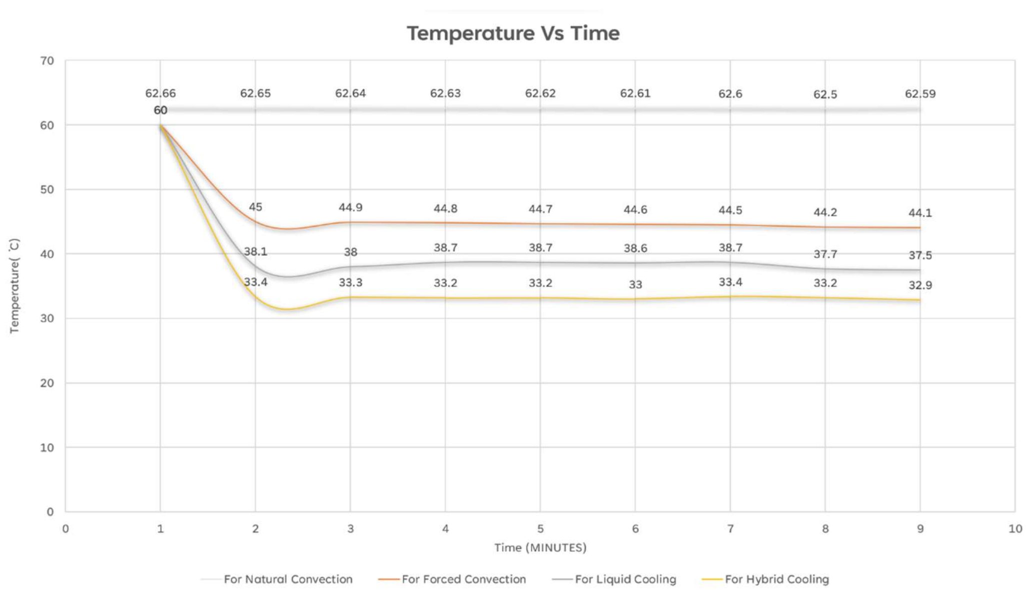


Figure 6.3: Temperature Vs Time Graph based on simulation Results

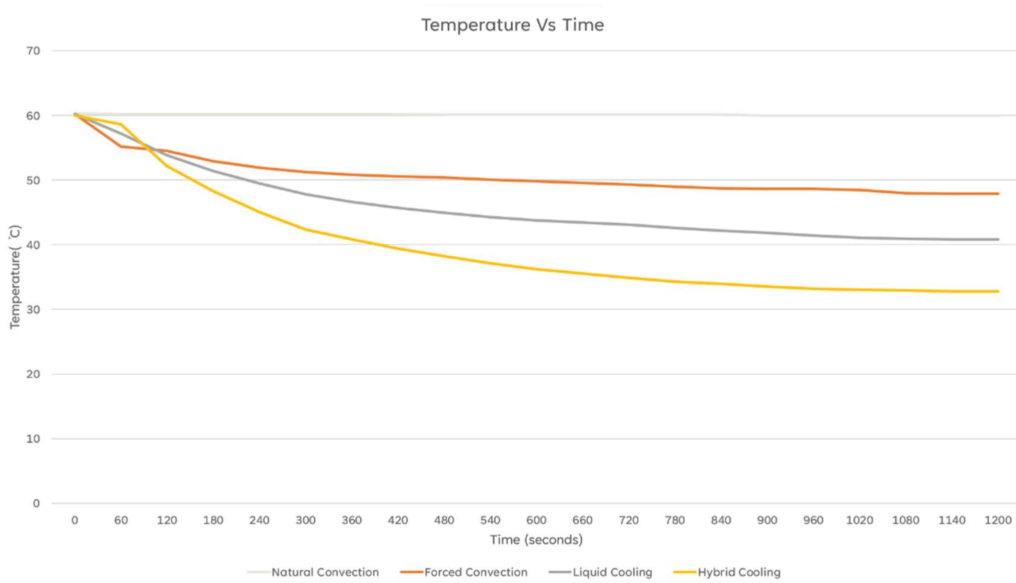


Figure 6.4:Temperature Vs Time Graph based on experimental observations

- The experimental study could be validated by the numerical analysis, which showed that the temperature reduction was about the same for both approaches. Overall, data shows that an approach to battery thermal management that combines liquid and air-cooling systems may be more successful and efficient.
- Although using fins to regulate thermal energy is a standard practise, it's necessary to take the needs of the system being cooled into account. The harsh discharge circumstances in this instance show the requirement for additional cooling techniques.
- The ability to analyse the thermal performance of the system in more detail and scope thanks to numerical analysis is a significant benefit. Before conducting any physical testing, this can assist in locating potential problems and optimising the design.
- A more balanced and efficient thermal management system can be achieved by integrating both air and liquid cooling techniques. This strategy can assist in making sure that the batteries are maintained within a safe temperature range even when running in hazardous settings.
- For batteries to operate at their best and last the longest, especially under difficult working conditions, efficient thermal management is essential. Depending on the needs of the battery, a combination strategy combining

both liquid and air cooling techniques can help to maintain a stable temperature range and avoid any damage.

- The system's thermal performance might be predicted and improved with the help of the numerical analysis. It is feasible to enhance the design and reduce the requirement for costly physical testing by understanding potential problems and testing various cooling solutions in a virtual environment. As a result, battery product time to market may be shortened significantly.

CHAPTER 07

CONCLUSION

CHAPTER 7

Conclusion

In conclusion, our thermal analysis of battery cooling using fins and a combination of air and liquid cooling methods has provided valuable insights into the system's thermal performance. Our numerical and experimental results showed that under normal operating conditions, the use of fins caused a temperature drop of 10°C due to air cooling. However, under severe discharging conditions, the temperature reduction provided by fins alone was insufficient to prevent battery damage. By incorporating both air and liquid cooling methods, we were able to achieve a more balanced and efficient thermal management system. We found that air cooling using fins was more energy-efficient due to its reliance on forced convection, while liquid cooling was more effective in extreme conditions. The effectiveness of the combined cooling method was validated through numerical analysis, which revealed a similar temperature reduction as our experimental results.

In forced convection we have achieved temperature drop of 11.6^0C , in liquid cooling method we have achieved temperature drop of 19.4^0C , while the most efficient method observed to be hybrid cooling with temperature drop of 27.6^0C , which clearly concludes that in extremely harsh conditions batterie’s safety can be managed by hybrid cooling method , on other hand air cooling or forced convection has proven to be most energy efficient .

From all the results and observations made we can conclude that , in normal working conditions air cooling is best method as it is energy efficient , while in moderately loaded conditions liquid cooling seemed to be the best way as it balances cooling to its energy consumption , while hybrid cooling is most energy intensive way but provides excellent cooling so it is best method of cooling in loaded conditions.

So, switching between these systems according to the temperature and load conditions on the battery has proven to be the best energy efficient way to implement in two wheeler’s battery cooling

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Links

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