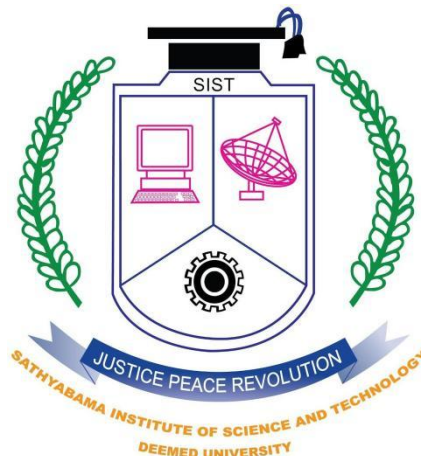


DESIGN AND FABRICATION OF LI-ION BATTERY COOLING SYSTEM FOR REDUCING THERMAL OVERLOADING

Submitted in partial fulfillment of the requirements for the award of Bachelor
of Engineering in Mechatronics

By

B.SHANMUKH VARUN TEJA (39090005)
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**DEPARTMENT OF MECHATRONICS
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with Grade "A" by NACC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600119**

MAY - 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **B.SHANMUKH VARUN TEJA (39090005), SK.BASHEER NAGOOR (39090049)** who carried out the project entitled "**DESIGN AND FABRICATION OF LI-ION BATTERY COOLING SYSTEM FOR REDUCING THERMAL OVERLOADING**" under my supervision from June 2022 to April 2023.

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DECLARATION

We **B.SHANMUKH VARUN TEJA (39090005)** and **SK.BASHEER NAGOOR (39090049)** hereby declare that the Project Report entitled “**DESIGN AND FABRICATION OF LI-ION BATTERY COOLING SYSTEM FOR REDUCING THERMAL OVERLOADING**” done by me under the guidance of **Dr.T.CHINNADURAI,M.E., Ph.D.** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Mechatronics.

1. 

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DATE: 10th May 2023

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ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the Board of Management of SATHYABAMA for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

I convey my thanks to Dr.S.PRAKASH, M.E., PhD, Dean, School of Mechanical engineering and Head of the Department, Department of Mechatronics Engineering for providing me with necessary support and details at the right time during the progressive reviews.

I Would like to express my sincere and deep sense of gratitude to my Project Guide Dr.T.CHINNADURAI, M.E., Ph.D., for his valuable guidance, suggestions and constant encouragement that paved the way for the successful completion of my project work.

I wish to express my thanks to all Teaching and Non-teaching staff members of the Department of Mechatronics who are helpful in many ways for the completion of the project.

I would also wish to thank my parents for all the tireless efforts they made for making me able to do what I do today.

ABSTRACT

Lithium-ion batteries are widely used in electric vehicles due to their more energy viscosity and long life. Lithium-ion battery performance and service life are very accurate to temperature, so maintaining the correct temperature range is important. Thermal management of the battery is essential for effective utilization in hot environmental conditions and for best life cycle. Improper maintenance and over-heating leads to thermal runaway which causes battery explosion. So, as to effectively improve the heat scattering performance of the battery cell is possible to obtain with the help of different cooling chambers in order to control its heavy temperature and temperature difference. In this paper, the closed chamber model of copper will surround the each battery cell to obtain maximum cooling. Taking temperature measurements with a temperature sensing elements and measuring the different flow rates of coolant with which the heating of the battery becomes normal and helps to extend the battery's longevity.

Keywords: Cylindrical Lithium-ion battery, Thermal management, Liquid cooling, Copper sheath.

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LIST OF ABBREVIATIONS

S.No.	ABBREVIATION	MEANING
1	EVs	Electric Vehicles
2	BMS	Battery Management Systems
3	ICEVs	Internal Combustion Engine Vehicles
4	SEI	Solid Electrolyte Interface
5	BTMS	Battery Thermal Management System
6	PCM	Phase Change Material
7	DOD	Depth of Discharge
8	VCC	Vapour Compression Cycle

CHAPTER-1

INTRODUCTION

Today, Lithium-ion batteries are the most widely utilized in electric vehicles. Battery technology has advanced dramatically in this decade and many high-performance batteries have been developed. High-performance batteries and appropriate battery management systems (BMS) are necessary for the reliable and safe operation of electric vehicles (EVs). For the battery systems of electric vehicles to maintain their energy storage potential, span, cell daily life, and security of the system, thermal management is critical. The battery cooling system is the most important thing in the electric vehicle industry today. However, this poses a major challenge to battery safety due to the increasing performance requirements of electric vehicles, such as long range and fast acceleration. This is because the temperature of the battery will continue to rise with the limits of space and time. accumulate during charging and discharging. When the safe temperature range (-20 to 60°C) is exceeded, heat escape may occur and consequent fire [1].

A battery cooling system is required to correct this battery fire problem. So in this article, we propose a new method of battery cooling system by which we can solve problems occurring in EV batteries. We need to monitor the battery and its temperature environment and their capacity [2].

From a long time the vehicles which are using combustion engine have stand for the most of the vehicles travelling on road. But how ever in recent years there is lot of changes and more development occurred by the new technology for batteries of EVs and the price of EVs decreased, while the percentage of EVs on the road greatly increased. while the last decade Globally, the amount of electric motor vehicles on the road developed greatly over 2010 and 2020, rising from less than 0.5 million to over ten million. Due to the environmental changes like green house gases, air pollution and climate changes which are occurring from pollutant coming from the IC engines may leads to severe environmental damages and reduces the air quality are the main reasons for the Increase of electric vehicles[3]. So according to a 2020 poll conducted in the U.S. describes that there is a serious decrease in the green house gases(GHG) pollution. Even they use fossil fuel powered power stations to generate electricity. In this study it shows that the

decrease of integrity The average number of deaths from air pollution has decreased from 65 deaths per 10,000 miles to 26 deaths per 10,000 miles. when ICEVs are phased out in order to support EVs. By knowing the safety of EVs it become a widely discussed topic due the increase interest because of its safety. The safety and performance can differ greatly as there is a lot of variety of options for the components are using in batteries. One such commonly used battery is the lithium ion battery [4].

In lithium-ion batteries it consists of some components like an cathode, anode, electrolyte and a separator. see Fig 1.1. While discharging the oxidized electrode which can remove the electrons to the external circuit is called anode. Correspondingly, an oxidizing electrode is a cathode that accepts electrons from an external circuit. The electrolyte will work as a medium between the electrodes to transfer the ions inside the separator and the cell to isolating electrodes[5]. A thin passive layer was created by the solid electrolyte interface (SEI) on the carbon anode's surface during the first charge. When the reaction rate slows down and it will decrease the current. Secondly, a Li-ion battery is a rechargeable battery which means electrochemical reactions in it are reversible. When charging Li-ion batteries disperse from positive to negative and when discharging it goes opposite negative to positive. Lithium-ion battery uses Interpolate lithium compound as the electrode in place of lithium [6].

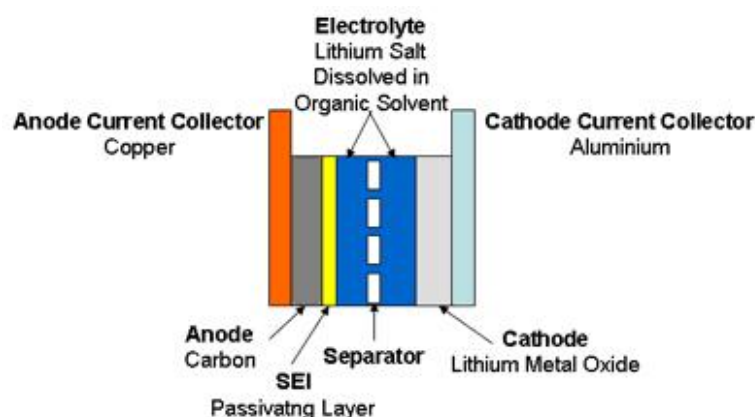
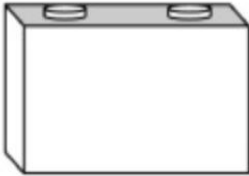


Fig 1.1: Lithium-ion battery physical structure

From what we know so far, there are several viable battery types in the EV sector, but in the market everyone will prefer Li-ion batteries as the mostly choice. Because of its high power density, energy and long lasting battery life lithium-ion batteries outperform many other batteries. There are several batteries that will

function with various materials. Each battery cell itself can be manufactured in a three kinds of different ways which are more commonly used in many automotive industries are Cylindrical cells, prismatic cells, pouch cells. One of the main differences in the geometry style as it suggests a name [7]. Each can hold a key parameters by the help of that can vary between different styles. Some Other differences such as the style sketches and the toughness are shown in the figure below.

Table 1.1: Battery cells cells in some different Styles.

Cylindrical cell	Prismatic cell	Pouch cell
		
• Small size (e.g. 18650 type (ϕ 18 mm, height 650 mm)) • Hard casing • Low individual cell capacity • Build in safety features • Comparably cheap	• Hard casing • Large size • High individual cell capacity	• Soft casing • Large size • High individual cell capacity • Geometrical deformation during (dis-)charging

Different electric car manufacturers use different styles. There are so many EV vehicles which are using lithium-ion batteries. Some examples are cylindrical cells used by the Tesla Model S, the prismatic cells are used by BMW i3, and pouch cells are used by Nissan Leaf. A pack of battery is a common term when thinking of electric vehicles. All the individual cells combinedly form a battery pack. Note that cells can be connected in parallel or in series, but the combination of the connections that can be combined. The connection of a series is created when more power is needed, and a parallel connection will be created when more capacity and current is needed [8]. A module is created when a certain number of cells are connected. The module is then connected to other modules to create the battery pack shown in Fig 1.2.

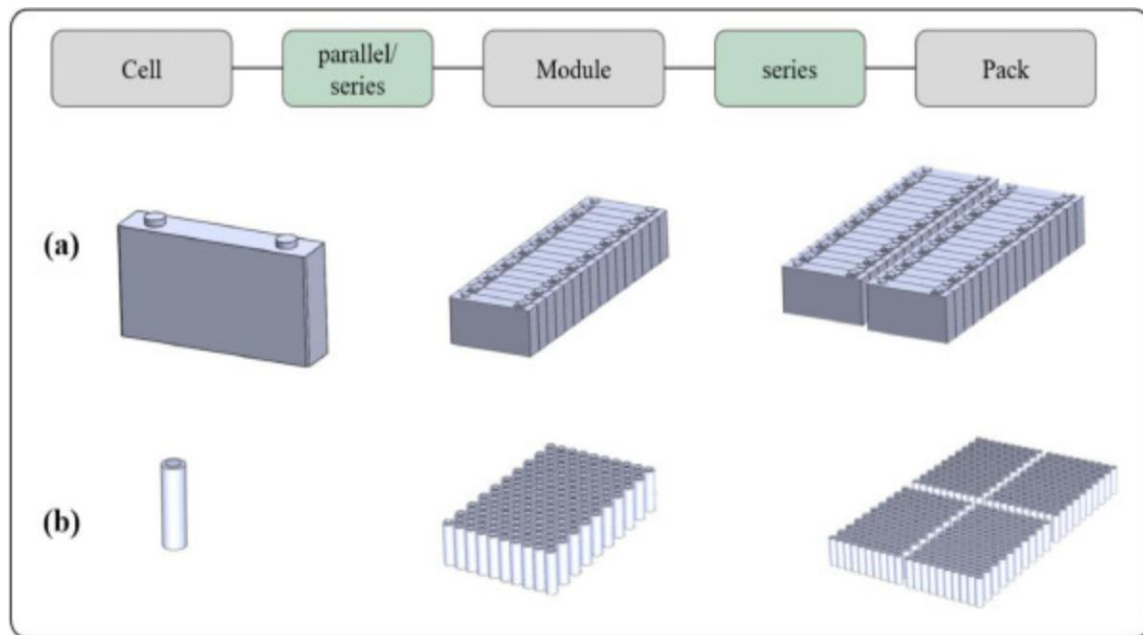


Fig 1.2: Battery cell, section, and set variations

1.1 TEMPERATURE ISSUES OF LI-ION BATTERY

A lithium ion battery's performance is affected by temperature and operating voltage. When the cell operated between limited voltage and within the temperature range. Otherwise, some irreversible damages will occur to the cells. In an over-voltage condition, the charge exceeds the voltage and the allowable voltage cell and an excessive flow of current, creating two problems in the same time. At excessive current, the lithium ions deposit faster than intercalate in the anode layer, and the lithium ions deposit as metallic lithium on the surface of the anode as a metallic lithium and this is called as lithium coating [9]. An irreversible loss of capacity, and the decrease in the free lithium-ions occurs due by it. Metallic lithium plating are of two types those are heterogeneous lithium plating and homogeneous lithium plating. Lithium plating has a dendritic shape. Eventually, a short circuit can occur between the electrodes. Considering overheating and cold temperatures, The operating temperature is so important for the life of lithium-ion batteries[10]. An acceptable temperature usual range is from -20 to 60 degrees Celsius. On the other hand, the optimum temperature range is usually from 15°C to 35°C. Using it from the outside of the allowable temperature can damage the battery and cause permanent problems. Performance is degraded when used at low temperatures. Among other things, the colder the

charging resistance, the longer the charging time. The risk of lithium plating increases when the plating penetrates the separator, reducing battery capacity or causing an internal short circuit. Aging will proceed if the temperature becomes too high. The estimated battery life will get reduced and reduces performance [11]. Higher operating temperatures also increase the risk of thermal runaway. Batteries themselves generate heat, so if too much heat builds up, an exothermic reaction will occur, further increasing the temperature.

1.2 THERMAL RUNAWAY

In relation to thermal runaway and other safety issues with lithium-ion batteries, where the various causes of that phenomenon. Thermal runaway is when a cell reaches a critical temperature and then the temperature rises spontaneously. In a lithium-ion battery, the solid electrode interface layer (SEI) begins to break down and an exothermic process releases heat when the cell reaches a temperature of about 80 °C. The anode's SEI layer serves as a protective layer that is created mostly during the initial charge-discharge cycles and is made of diverse materials such as Li ions [12]. As the temperature rises from 100°C to 120°C, another exothermic reaction begins in which the electrolyte decomposes and, depending on the cell chemistry, begins to produce gases such as carbon dioxide or methane. When the cathode and anode make contact at 120 to 130 °C, the barrier in the electrodes melts, leading to a short circuit within the device and more heating. The electrolyte and cathode continue to break down after the temperature hits 130°C to 150°C [13]. During this highly exothermic reaction, oxygen escapes. the lithium generates a great deal carbonate electrolyte and oxygen productions what ultimately causes the cell to ignite. The final highly exothermic reaction can reach temperatures of 150°C to 180°C, making the reaction autonomous. When a reaction becomes It is categorized as a thermal runaway since it is self-sufficient. While this is occurring in one cell, nearby cells are being heated up by the newly created heat. As a result, the identical series of events take place in more cells, spreading the production of heat. When cells within a module generate enough heat, it can spread throughout other modules and packages. It's important to remember that if a fire breaks out, putting it out doesn't solve the problem [14]. In fact, chemical reactions can take place inside that can generate heat again,

eventually leading to the process of re-ignition. A general timetable for the progression of thermal runaway is shown in Fig. 1.3, along with the duration of each phase of the reaction.

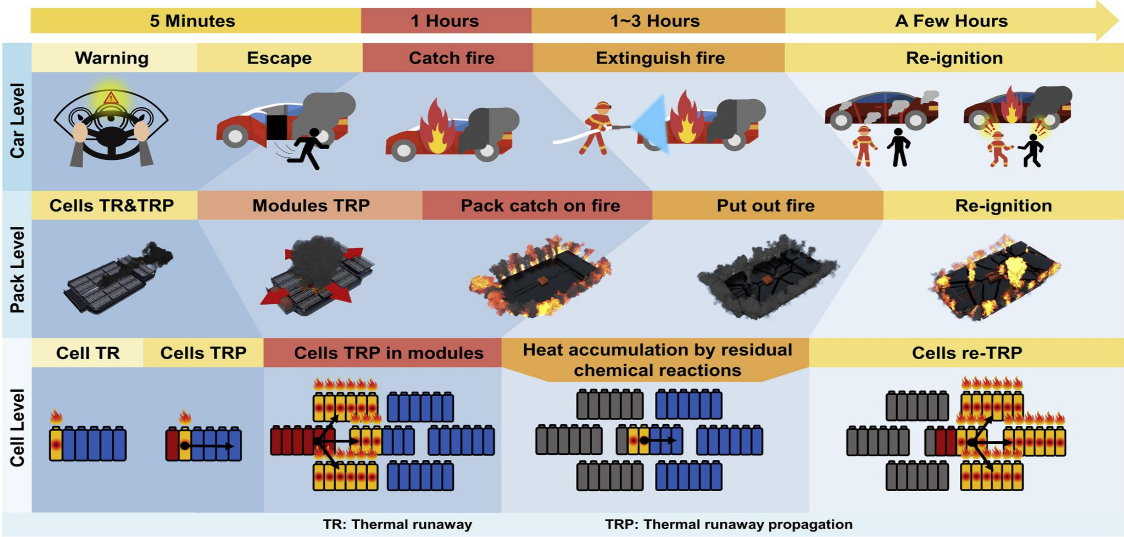


Fig 1.3: Thermal runaway propagation.

If thermal runaway is happening or has already started, there are ways to prevent it from spreading. Fig 1.4 shows an example of how the propagation velocity can be stopped and reduced to allow It's time to let the passengers out of the car [15]. The primary safety technology focuses on cooling by the battery thermal management system (BTMS) of the vehicle and insulation between cells and modules.

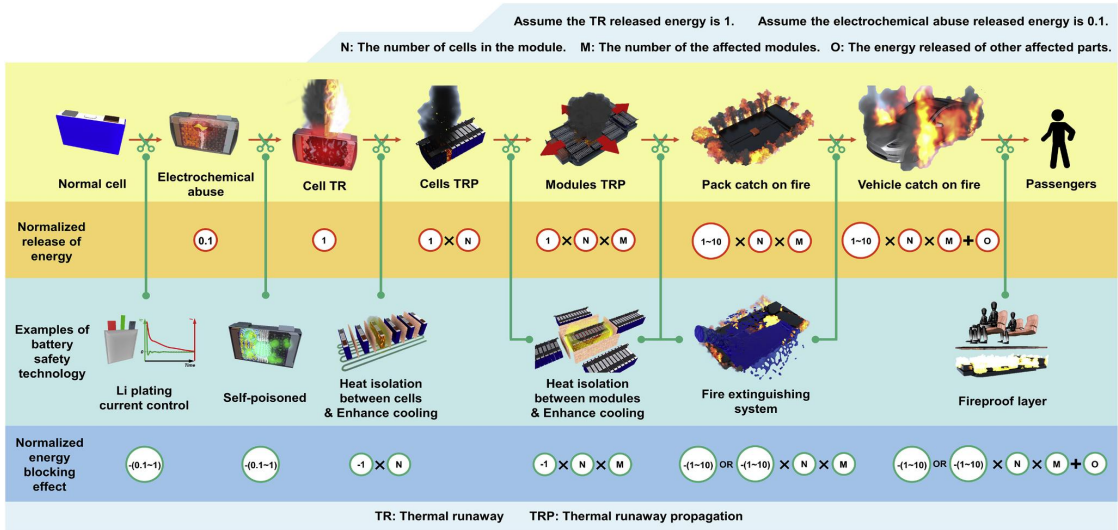


Fig 1.4: How to stop the effects thermal runaway propagation.

1.3 BTMS

Therefore, today the main topic and it is very crucial thing for many of the researchers and companies is all about developing an effective and impact-full cooling system for controlling the temperature of the batteries with in a specific intervals in temperature. To develop an effective battery thermal management system. It needs a considerable and more efforts have been committed towards that[16]. The BTMS battery thermal management system, it can be broken down into a number of smaller groups, each with its own benefits and drawbacks, such as passive and active cooling, internal and external, series and parallel, air, liquid, and phase change material (PCM), vapour compression and the heat pipe. Fig 1.5 is classified about different types of the BTMS excluding the vapour compression solution .

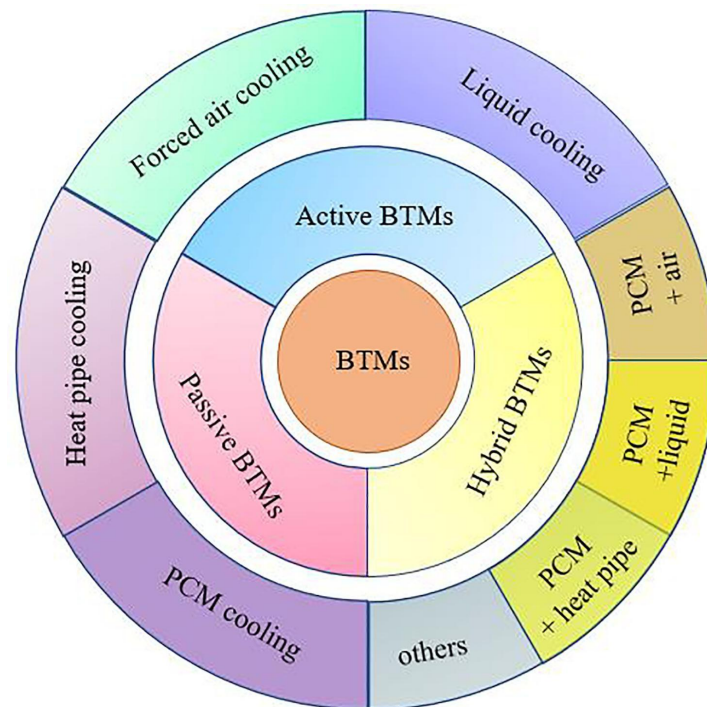


Fig 1.5: BTMS can be classified into different types.

1.4 COOLING SYSTEMS

1.4.1 Cooling with liquid

Liquid cooling is a procedure that provides a more effective way to control temperature. The goal is to locate a cooling system, as the name suggests that

can control both consistent temperature decline and heat transmission. Since the liquid-cooled kind has the temperature distribution of the battery pack is better than the air-cooled type in both terms of thermal conductivity and heat capacity.. It functions by removing heat from radiating components utilised in places where heat is required (or dissipated into the environment). Direct cooling and indirect cooling are two categories of liquid cooling technologies. Battery immersion is the procedure we use to cool the entire battery surface. Direct cooling. The original version of the idea involved encircling the cell with a flat aluminium tube. Each tube has a number of tiny liquid flow channels, which increases the effectiveness of heat transfer[17].Due to the stringent waterproofing requirements of the battery system, this type of system is less frequent in automotive battery cooling systems. Otherwise, an electrochemical reaction or electrical short circuit might happen. Moreover, it only functions when there is power. Thermal management prohibits the integration of heaters below 0 degrees. Since then, there has been documentation of them. Systems like tube cooling and cold plate cooling fall under the indirect cooling category. This kind of system is more simpler to set up and has higher cooling capacity, average energy efficiency, and safety usage.A metal plate having tubes or channels inside is termed a cold plate and is used for indirect cooling[18].Then, position the cold plate and battery cell so that parts of their surfaces are in contact with one another. 50 10 Ah pouch cells made up the battery pack in one experiment. These heat transfer was made easier and the temperatures of the cells kept constant by enclosing them between two heat spreaders.

1.4.2 Air Cooling

Air-cooling fig 1.7 qualities include simple attachments that are inexpensive and lightweight, as well as ease of maintenance. In commercial Evs the most popularly used technology for battery cooling is Air cooling because of its benefits. Toyota Prius Prime, Honda Fit EV, Hyundai IONIQ, Nissan Leaf, and others are a few examples. There are two types of categories present in air-cooling system that involves forced and natural convection. The natural convection type will work by cooling the battery pack using the outdoors and interior natural air.Forced convection is typically used in conjunction using the HVAC system's evaporator or condenser to circulate air into the battery container[19]. Natural convection is more

effective than both heated air and natural convection. without any opening of vents when it comes to the waterproof department. The downside, for the battery heat dissipation however by the natural convection cooling is invalid. The forced convection cooling will be used in various models, including the Hyundai IONIQ and Honda Fit EV.

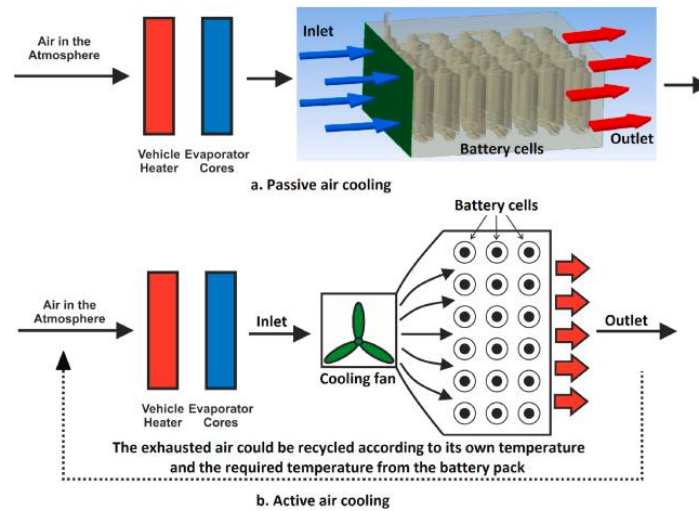


Fig 1.6: Symbolic diagram of the air cooling system

1.4.3 Phase Change Material (PCM)

The main thing is the heat absorbed by the battery pack and change the phase of it is done by special material which is used in the PCM. There are two different ways are present in storing the energy for this specific method. At starting the material will only store the sensible heat by absorbing the heat purely then temperature in it will increase by its own to determined that by this process and it will be limited by its heat capacity and it can be stored in it. For choosing a material the sensible heat is nor primary reason or critical allot as it will be noted. Latent heat is the most important aspect and the another way of PCM for storing the energy[20]. If a stored latent heat is changing then the material will automatically change its phase. From the environment the heat that can be kept or released in a sustainable manner by this phase changing material by the case of lithium ion batteries in electric vehicles. Material temperature change is negligible when the phase change is occurred. Latent heat is a greater storage capacity of heat energy, the more important aspect for a material is all about controllability of temperatures during the phase change materials. It is stated that the PCM is a passive battery thermal management system, both more parts and additional

energy are not needed for it to function such as electricity. The change of the materials will happens between solid- liquid or it may from liquid-solid are the two main categories in the phase change materials. Heat pipe is another type of BTMS which is used as well as preferred as phase change liquid (PCL) with relation to the liquid to gas phase shift [21].

The phase transition of solid and liquid case it is arranged as seen in Fig. 1.7, the area where the batteries and the components are in direct touch with one another. Due to the materials' direct contact, when the thermal load increases quickly, PCM must keep the desired temperature. One further significant result that can be obtained is a temperature that is uniform.. Heat from the environment is absorbed by the material as it will melt as absorbing the heat of the batteries too. Phase change method is mainly used in warmer climates in a long period of time. Instead of the cooling battery pack from the environmental temperature the materials will get a risk of melting. PCMs can be sub divided into 3 major categories are organic , Inorganic and eutectic PCMs [22].

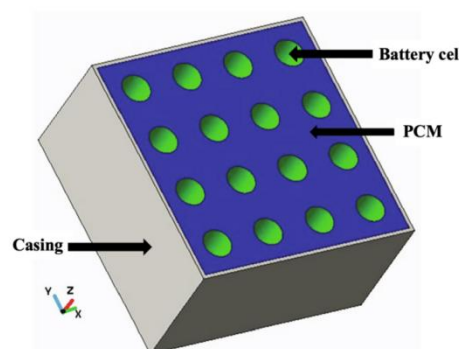


Fig 1.7: The image of PCM inside the battery pack

The fact that both organic and inorganic materials have similar phase change temperatures, latent heats of fusion, and thermal conductivities. PCMs are set for a particular material is a disadvantage. In this situation, eutectic PCMs may be used. Eutectic PCMs can be made particularly for desired qualities by combining several organic and/or inorganic PCMs. In this manner, the material can have the ideal latent heat of fusion and phase transition temperature for its application. These materials have some drawbacks, including the fact that they are more expensive and not always readily available compared to more prevalent materials like paraffin wax [23]. Be aware that many metallic PCMs, which also have improved thermal stability, make up of modern PCMs.

1.5 LIQUID COOLING PROFILES

The heat pipe system was gradually assessed as the full system was put together. The system level (whole system), module level (HPCP, RHE-HP), and component level (heat pipes) evaluations are included in this. The thermal qualification of each heat pipe is the first stage at the component level in order to meet the overall target maximum cell temperature of 80 °C at the casing for 50W heat load per cell, as per thermal modelling in Fig. 1.8. Heat pipes with the ideal water charge and shape were tested in locations corresponding to those predicted in the actual system, as needed by the overall design. to confirm that the heat pipes' thermal resistance complies with design requirements and to determine the maximum heat transfer the heat pipe qualifying capability, to outline operating constraints, and to remedy any unforeseen design defects [24]. This arrangement for cooling plate heat pipes uses three evenly spaced cartridge heaters enclosed in a copper block and a heat load simulator to uniformly heat the evaporator. The condenser is cooled by natural convection using a metal heat sink. Thermocouples were installed on the heat pipe's surface to measure its thermal resistance and thermodynamic behaviour. When tested in the assembly orientation for which they were designed, RHE-heat pipes performed flawlessly. A heat load simulator with thermal load was used to provide heat to one leg of a U-shaped heat pipe in place of an aluminium heat sink with two axial flow fans acting as the heat sink. It should be emphasized that in order to certify heat pipes, either forced or natural convection using a fan was used, depending on the test heat load.



Fig 1.8: Cooling fins

It was discussed the thermal behaviour of battery modules with various circular, hexagonal, and rectangular battery cell arrangements. When all costs are taken into account, the 5 x 5 cubic construction has the best cooling capacity, and when space utilization is taken into account, the 19 batteries arranged in a hexagonal

arrangement have the best cooling capacity. Fan built the battery pack shown in Fig. 1.9 using 32 high-energy-density cylindrical lithium-ion batteries that were arranged precisely, staggered, and crossed. Using a set of evaluation criteria, the effectiveness of air cooling and energy efficiency of various battery pack arrays at varied intake velocities were compared[25].The results show that the optimum cooling performance and temperature uniformity are achieved by a battery pack that is neatly placed, followed by a battery pack that is staggered and then cross-arranged. When items are carefully organised, the least amount of power is used—23% less than when things are stacked horizontally. It was found that the cooling performance of the thermal management system may be improved by optimising the geometric size of the airflow route. To test the battery box's air-cooling capacity at various air volumes and flow rates, forced air cooled a high-density battery box.It has been discovered that while the maximum temperature steadily fell with an increase in cooling route size, The level of cooling steadily dropped.Chen optimized the breadth of the airflow inlet and outlet to considerably increase the effectiveness of a BTMS with parallel U-flow air cooling [26]. When the optimized battery pack is discharged at a 5C pace, the temperature difference between the battery cells is reduced by 70% and the power consumption is reduced by 32%. The outcome of using this method is more obvious than it would be if the battery spacing were changed. The volume averaged temperatures of the flat-plate battery stacks remained largely constant when changed the cooling channel size and the quantity of cooling channels for stacks with the same channel size and cell volume ratio. Additionally, it was found that expanding the cooling channels could improve cooling performance but would cause an uneven distribution of temperature inside the battery unit. Consequently, it's crucial to determine the size of the cooling channel.

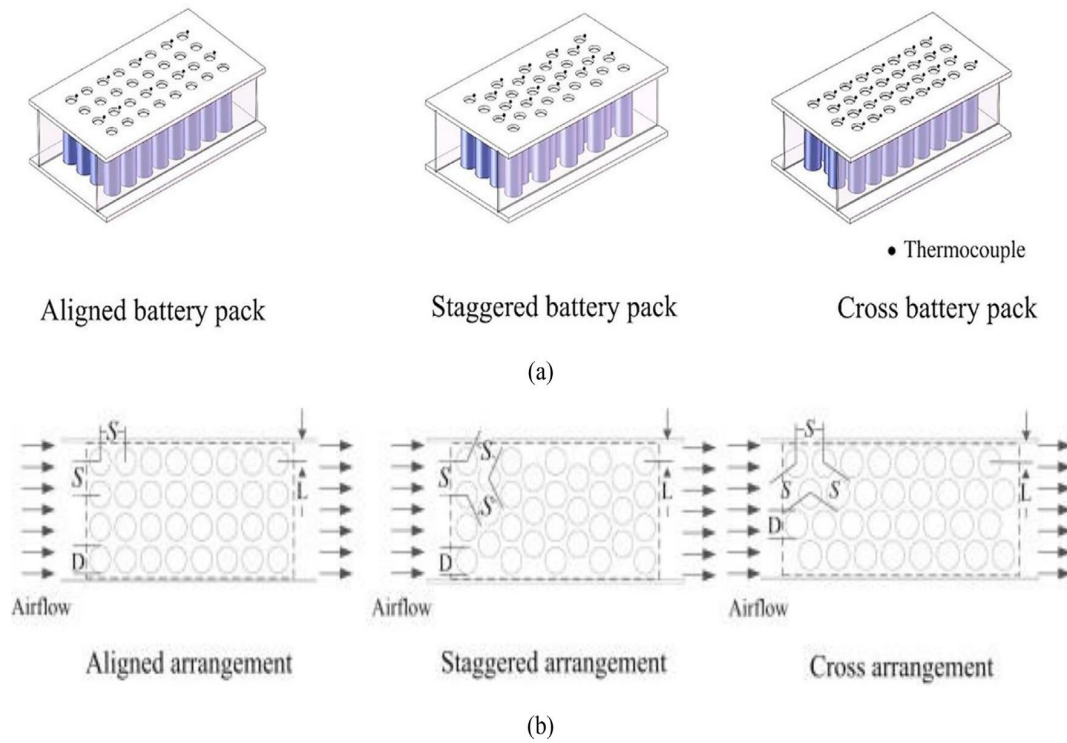


Fig 1.9: (a) An illustration of battery packs placed crosswise, staggered, and in alignment.

(b) Three battery packs are stacked in a structure.

Cold plates and rectangular channels were used in proposed BTMS. As illustrated in Fig 1.10, position the next pair of cooling path on the other side of the cooling plate, with the battery sandwiched between two cooling plates and the circulating liquid passage set up as a rectangle. The experiment revealed that the refrigerant flow and channel count were the two main factors affecting heat dissipation. Height and channel width are supporting elements [27]. The cooling plate's average temperature and temperature differential are at their lowest when the channels have dimensions of 45 mm in width, 5 mm in height, 4 in number, and 0.07 m/s in coolant flow rate. The examination of the cooling performance of liquid-cooled BTMS has advanced thanks to the use of the flow route shape and fluid flow distribution. Suggested a cylindrical battery cooling solution based on micro channel liquid cooling. The maximum temperature of the battery module can be kept below 40 °C if there are more than four microchannels and the inlet mass flow rate is adjusted to 1103 kg/s.

Although maximum temperature steadily drops as the number of microchannels in the LCC rises, the channels' total number shouldn't surpass 8. K. Li created a

powerful micro channel cooling system and refined it to achieve four goals: reducing temperature difference, Standard battery pack size, pressure drop across cold plates, and temperature difference. According to the trial results, the pressure drop was decreased by 44.53%, the ideal battery pack temperature difference was lowered by 5.07%, and the standard temperature difference was reduced by 0.82%.[28] As part of his investigation into liquid cooling methods, he used different cooling plate devices that included integrated ice trays and cold plates. The integrated ice tray's cooling capacity was found to be superior when the two cooling capabilities were compared. With the integrated cold plate, which is less expensive and easier to use, the coolant circulation rate is higher. Cao claims that adjusting a coolant channel manifold allows for an optimal flow distribution, which in turn affects the temperature homogeneity across battery modules[29]. They compared it to the battery pack for the original channel manifold and suggested a way to modify the manifold using a T-joint. When the battery pack was discharged at 1C while receiving an 18 L/min coolant flow, the three-dimensional temperature distribution of the battery pack is depicted in Fig. 1.7. With a 2C discharge and flow of 36 L/min, the working temperature and thermal homogeneity could be kept within the appropriate temperature range.

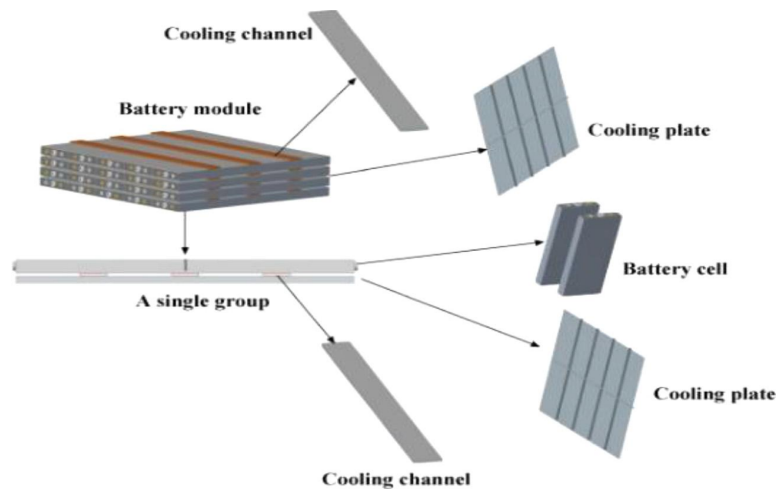


Fig 1.10: Model for liquid-cooled batteries with cold plates and rectangular flow channels.

CHAPTER-2

LITERATURE REVIEW

2.1 THERMODYNAMIC MODEL AND PROBLEMS

The most crucial component of EVs is the battery, which performs numerous cycles of charging and discharging in the course of its lifespan. Understanding how heat is generated inside the battery is essential because Li-ion batteries' efficiency is closely tied to temperature. Li-ion battery heat generation is a challenging process that necessitates understanding of both the electrochemical reaction's time and temperature dependence as well as the current flow through the battery [30]. Li-ion batteries are known to generate heat via chemical processes, resistive dissipation, relaxation of the cell's concentration gradient, and reversible entropy.

When charging and discharging, Li-ion batteries typically produce three types of heat: activation irreversible heat caused by the electrochemical reaction polarisation, joule heating resulting in ohmic losses, and reversible reaction heat brought on by entropy change. Therefore, the battery's temperature may increase as a result of heat accumulation if the heat generated by the battery during charging and discharging is improperly dissipated, which could negatively impact battery performance, life, and safety. Loss of capacity and power can be used to describe a decline in Li-ion battery performance [31].

The battery's capacity decreases as a result of the active material's transition into an inactive phase and the subsequent rise in impedance. However, it is clear that the performance of Li-ion batteries is influenced by the operating temperature. It is difficult and challenging to specify the precise and specific capacity/power reduction mechanism. In contrast to capacity fade, power fade is a strong function of DOD, and these losses are temperature independent of minute DOD changes, claims the research [32]. Another important problem is the thermal runaway that develops as a result of the heat from the Li-ion batteries. When the rate of temperature rise is sped up, thermal runaway happens, and it can have disastrous effects like rapid temperature rise, gas production, and even battery explosion.

This phenomenon has a significant impact on the safety of vehicles and passengers. To reduce the possibility of thermal runaway, Li-ion batteries have a number of safety measures, such as safety vents, thermal fuses, automated reset devices, shutdown separators, chemical shuttles, coatings, and electrodes and electrolytes that can withstand heat. The fundamental cause of thermal runaway, battery cell temperature inconsistency, must be avoided in addition to these safety measures.

The battery cell may have an uneven temperature distribution as a result of its thermal resistance and internal heat-producing region, which may be significant for issues with performance, safety, and ageing. Therefore, when designing and refining BTMS, it is crucial to consider both reducing temperature disparity and avoiding an excessive temperature rise. The specific thermal runaway process of Li-ion batteries has been reviewed [33]. In addition to the problem of temperature non-uniformity and rapid rise, the energy and power capabilities of Li-ion batteries significantly fall when operating at low temperatures.

The common causes of Li-ion batteries' performance decline at low temperatures include solid electrolyte interface film, surface charge transfer impedance, and lithium solid diffusion in electrodes. There are numerous methods, such as preheating, heating plates, and air conditioning (AC) heating, to lessen harmful effects at low temperatures. In order to considerably enhance low temperature performance and it is examined the performance of a 35Ah high-power Li-ion battery in a low-temperature setting and offered a broad line metal film heating technique for battery heating [34]. When the charge/discharge performance of the cell was evaluated at various constant currents and temperature ranges between 20 °C and -40 °C, the discharge capacity of the cell declined as the temperature increased.

When under 0 °C, the charge did not work adequately. The suggested heating procedure, however, could be able to improve these performance declines. For EVs, the BTMS that maintains the battery's proper temperature range and temperature uniformity is necessary to avoid the thermal issues with Li-ion batteries that were previously described. The importance of BTMS has increased due to the tendency of packing more battery cells with higher energy densities

than before into the pack and charging the battery more quickly by applying a higher current because it causes the battery to heat up more [35].

2.2 BATTERY COOLING SYSTEMS ARE CATEGORIZED

The fundamental responsibility of the BTMS is to keep the battery cells, modules, and pack within an ideal operating temperature range and with a uniform temperature distribution even under rapid charge/discharge rates and harsh weather conditions. The BTMS should perform the following four crucial tasks, according to Psaran (2001): Cooling is used to remove heat from the battery, heating is used to increase the temperature of the battery when it is too low, insulating is used to avoid an abrupt shift in battery temperature, and venting is used to release any potentially toxic gases from the battery. In order to be applied to EVs [36]. Moreover, BTMS should be small, light, affordable, highly reliable, simple to maintain, consume little parasitic power, and be simple to pack. With the exception of an EV's initial operation in a cold ambient environment, this study concentrates on the battery cooling system due to the large temperature rise caused by battery heat generation.

Several categories have been used to categorise battery cooling technologies. Fig 2.1. Secondly, there are many types of battery cooling systems, such as liquid cooling, air cooling, and PCM cooling. Another aspect to take into account is power consumption [37]. While passive cooling only makes use of the surrounding environment, active cooling uses an energy source. The medium's direct or indirect contact with the battery serves as the deciding factor between direct and indirect cooling. The vapour compression cycle (VCC) is used by some BTMS, but it is not used by others. Three technologies make use of the VCC: direct refrigerant two-phase cooling, secondary loop liquid cooling, and cabin air cooling.

PCM cooling, thermoelectric element cooling, and heat pipe cooling are among the cooling technologies not utilizing the VCC. All types of vehicles are equipped with the functionality of a car's air conditioning system. In order to maintain a comfortable environment for passengers while running the vehicle in a variety of weather situations, it regulates the air temperature via heating and cooling. BTMS and VCC integration is used in many EVs because it can be integrated into existing systems [38]. A number of cooling system structures are shown in Figure 2.1.

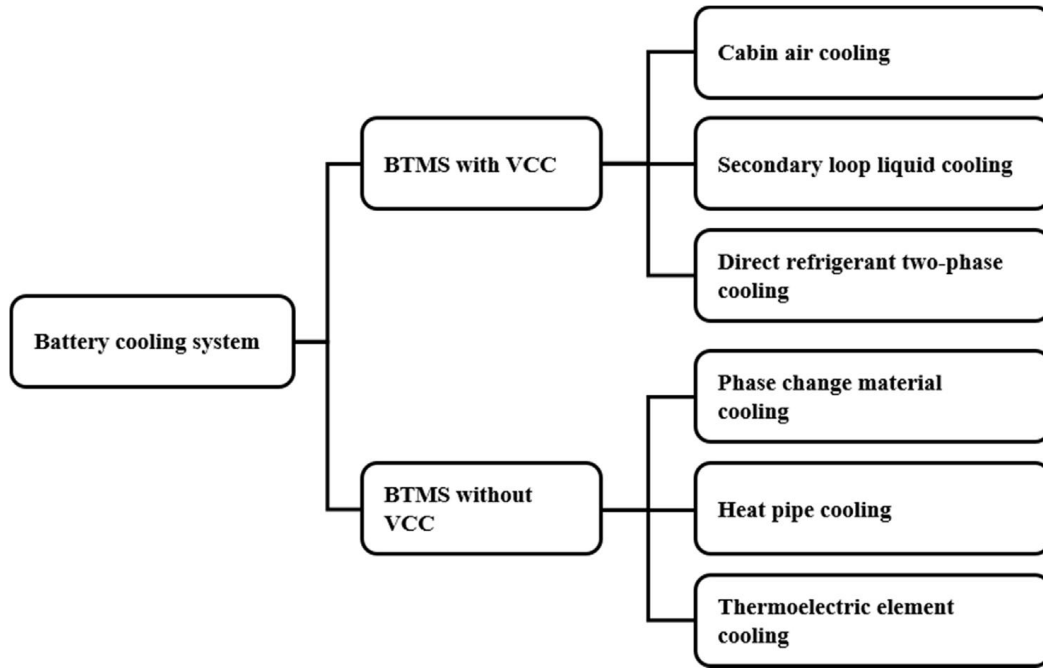


Fig 2.1: Classification of battery cooling systems.

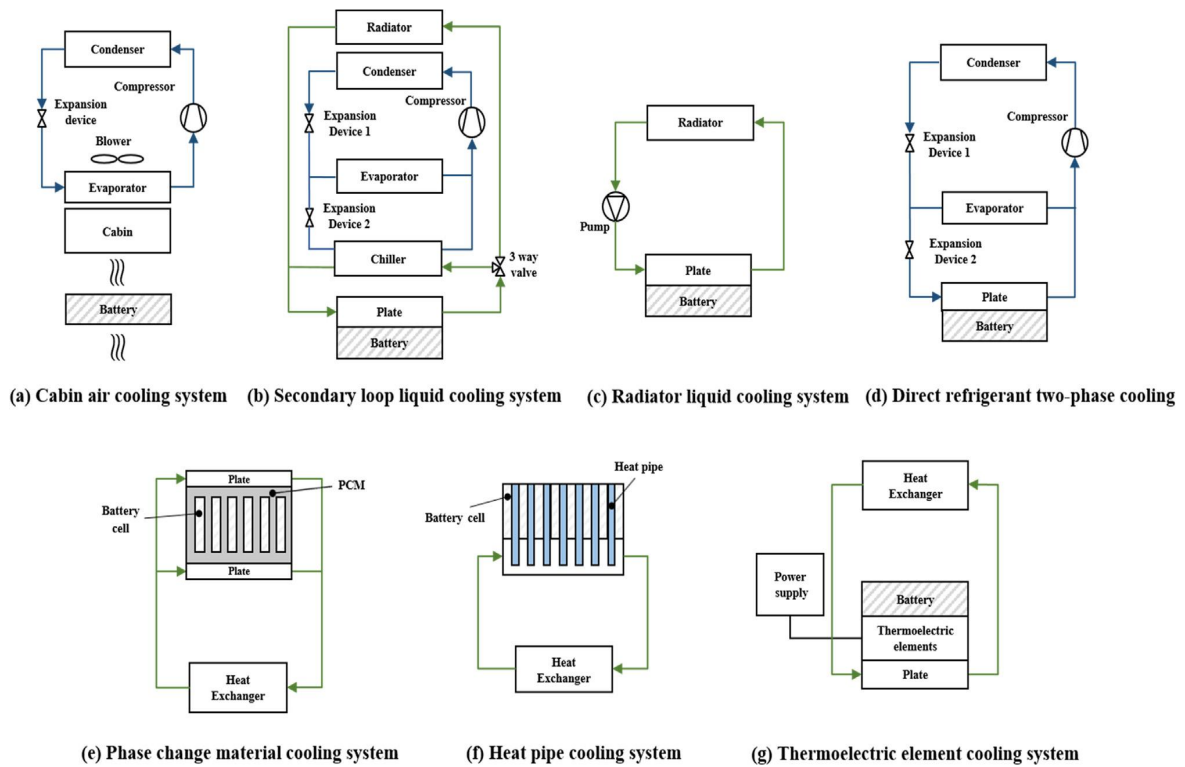


Fig 2.2: Diagrams for various battery cooling systems.

CHAPTER - 3

AIM AND SCOPE

3.1 AIM

The goal of this project is to design a battery cooling system that provide an efficient and cost-effective solution for maintaining the optimal temperature range of batteries during charge and discharge cycles. The primary goal of this project is to design, develop, and evaluate the effectiveness of the battery cooling system in maintaining the optimal temperature range of the battery when used with both water and ethylene glycol as coolants [39].

3.2 SCOPE

The scope of the project includes the design, development, and testing of a newly designed battery cooling system that can be used with both water and ethylene glycol as coolants. The project will involve researching and selecting the most suitable components, such as sensors and controllers, to integrate the management system with the battery pack. The report will also cover the testing and validation process, including the collection and analysis of data to evaluate the system's effectiveness in maintaining the battery's optimal temperature range with both coolants [40]. The project will also investigate the cost-effectiveness and energy efficiency of the management system with both coolants, including their environmental impact. The report will include recommendations for improving the system's performance and reliability while minimizing its maintenance requirements.

The newly designed battery management system has the potential for further development and improvements to enhance its functionality, efficiency, and usability. Some of the potential future scope for the system include using dielectric fluids to minimize the risk of short circuit, Integration with advanced sensors and machine learning algorithms to enable real-time monitoring and prediction of battery performance and health and development of an advanced user interface that can provide the user with real-time feedback on battery performance, charging/discharging status, and temperature management [41].

CHAPTER – 4

EXPERIMENTAL SETUP AND METHODOLOGY

4.1 EXPERIMENTAL SETUP

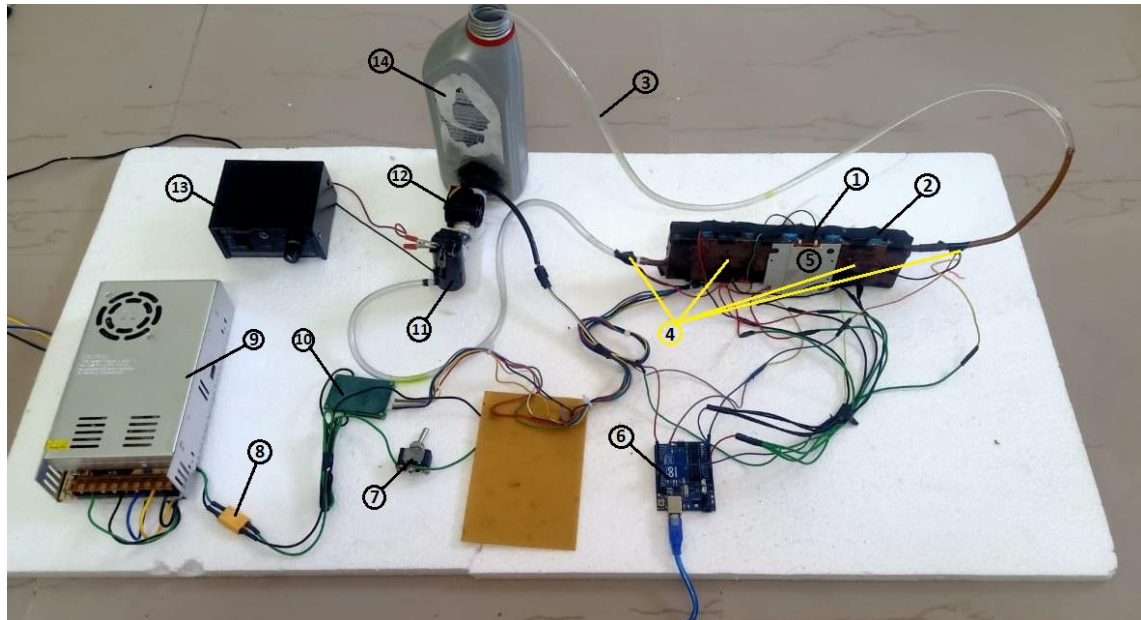


Fig 4.1: Experimental setup

- 1 - Copper chamber
- 2 - Batteries
- 3 - Tube
- 4 - Four temperature sensors
- 5 - Heating Coil
- 6 - Arduino
- 7 - One kill switch
- 8 - Battery Male Female Connector Plug
- 9 - 21V 15amps power supply
- 10 - Battery Management System
- 11 - 12v dc water pump
- 12 - Flow sensor
- 13 - Battery Eliminator
- 14 - Tank

4.2 METHODOLOGY

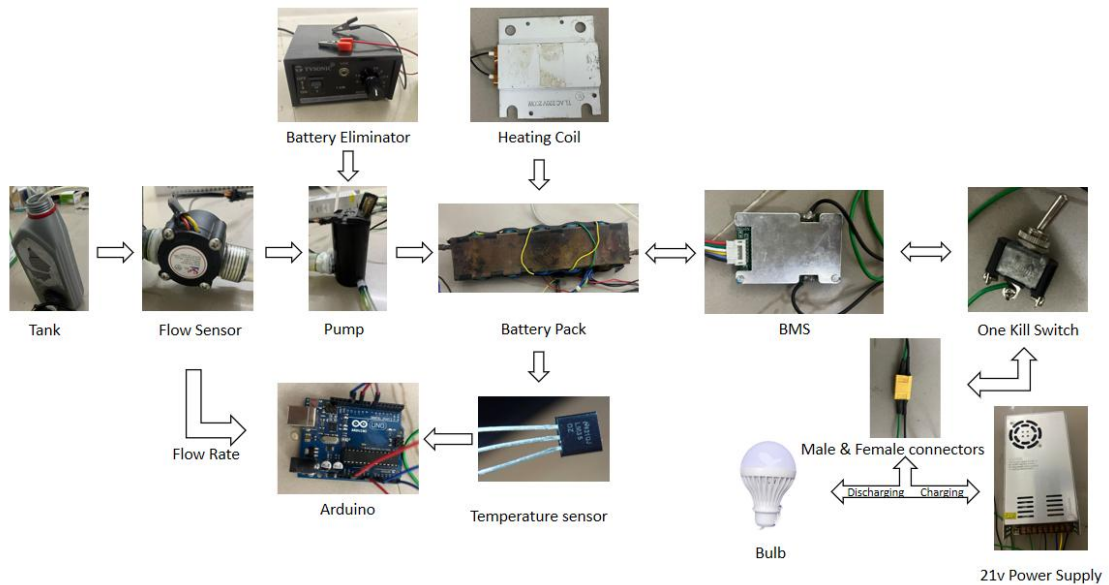


Fig 4.2: Block diagram

Mostly, now a days Li-ion batteries are used in electric vehicles but they are getting exploded due to thermal overloading. So in this experiment we are proposing a new innovative method of battery cooling system which helps in reducing the thermal over loading [42].

First, we performed an experiment on the cooling system of a Li-ion battery to reduce thermal overload. In this experiment, we use materials such as Li-ion batteries with configurations of 3.7 V and 2000 mAh rechargeable batteries. We used the copper tubes with the diameter of 0.7mm and 1cm. with the help of this copper tube we made a cooling system. Like at both the top and bottom for inlet and outlet we used 2 copper tubes with the diameter of 1cm.

In the setup shown above in that we placed a Li-ion batteries which we are going to cool down with the help of coolant and we inserted the batteries according to the correct fitted size . According to the size and width and height of the batteries we prepared a copper chamber for placing batteries into it. We must to check the leakages of the system with any fail. After placing the batteries we applied some lubricant gum Adelaide to rescue from the leaks in it so places the batteries in a series order like top of the battery is in upside and bottom is in downside for every cell before performing the experiment.

Then we heat the batteries using heating coils, and we measure the temperatures of the batteries using temperature sensors. We utilized Arduino to provide the code to verify the temperature and flow of the cooling system. The 12v dc motor pump is operated by a battery eliminator with the aid of a power source. To make the charging and discharging process continuous, a 21v 16Amp power source is utilized to charge the batteries, and a Dc motor is used to discharge the batteries [43]. The usage of a battery management system helps to lower the risk of the battery when this process is taking place by providing an equal and controlled supply of charge and discharge as well as controlling overheating. Since that the ambient temperature can reach up to 30-35 degrees Celsius, we employ external heat by using a heating coil to warm the battery up to 60 degrees Celsius. The sensor measures the battery temperature values. Lm-35 temperature variable. Four temperature sensors have been used in the test because the first sensor is at the copper tube's opening where the coolant first enters, the second sensor is in the second battery, the third sensor is in the fourth battery, and the final sensor is on the fifth battery. last sensor is located at the exit of a tube. We used a 21v 1600amp power source for charging and discharging, which allowed us to use a 60W light to charge and discharge the battery.

The Arduino Uno controller has a request code that can be used to measure the flow and temperature readings related to the battery management system. Coolant enters the experimental setup through the flow sensor, travels to the inlet, and exits through the outlet. This procedure is repeated until the batteries reach their usual state at 60 degrees Celsius. As we experimented at a range of flow rates, including 12v, 9v, 7.5v, and 6v, with corresponding 60° and 30° constant ambient temperature. When the battery is in a normal state, we take the corresponding reading after cooling it and examine the cooling conditions of the battery by varying the flow. Calculate the amount of time needed to transition from the heating position to the normal condition so that the normal inlet coolant temperature and outlet coolant temperature are equal.

4.3 MATERIALS AND COMPONENTS

4.3.1 Lm-35 Temperature sensor

The LM35 is a temperature sensor that converts temperature into an analog voltage output, with a linear output voltage that changes by 10mV per degree

Celsius. It has a temperature range of -55°C to $+150^{\circ}\text{C}$ and high accuracy of $\pm 0.5^{\circ}\text{C}$ at room temperature. It is easy to use and requires minimal external components. It is commonly used in temperature control and monitoring applications.

The LM35 is a versatile and accurate temperature sensor that is widely used in various applications. Its linear output voltage, wide temperature range, and high accuracy make it suitable for both hobbyist and industrial applications. The LM35 is easy to use and requires minimal external components, making it an ideal choice for temperature control and monitoring applications.

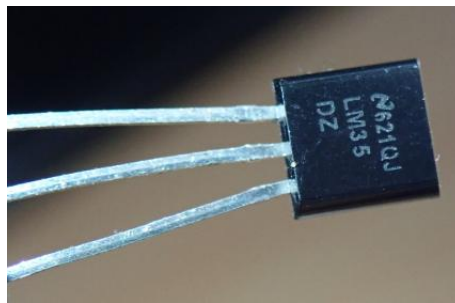


Fig 4.3: Lm-35 Temperature sensor

4.3.2 Flow sensor

A flow sensor is a type of electronic instrument which measures or governs the flow rate of liquids and gases through pipelines and tubes.

A wide range of flow sensors are available to meet specific needs and uses. The following are the most prevalent factors that will influence the sort of flow sensor you require:



Fig 4.4: Flow sensor

4.3.3 Power Supply

21V 15amps power supply used for charging of the battery. An electrical device that supplies electricity to a load is referred to as a power source. The main job of a power supply is to convert the source's electric current into the right voltage, current, and frequency for the application. Power sources are hence sometimes referred to as electric power converters. While some power sources are independent devices, others are built into the loads they power.



Fig 4.5: 21V 15amps power supply

4.3.4 12v dc water pump

Pump motor that can be powered by a 12V power source is used to move fluids through it at specified pressure levels. Smaller direct current (DC) motors are frequently used in the manufacture of appliances, tools, toys, and automotive devices such as electric car seats, whereas bigger direct current (DC) motors are used in hoists, lifts, and electric vehicles. A 12v DC motor with a highest capacity of 1.5A can produce 18W of power. A 12v DC motor with a highest capacity of 3A can produce 36W of power. Brushed and brush less direct current motors can both be used as generators.



Fig 4.6: 12v dc water pump

4.3.5 Battery Management System

A Battery Management System (BMS) is an electronic system that monitors and controls the charging and discharging of rechargeable batteries. It manages the battery's state of charge, state of health, and state of function to ensure safe operation, prolong its lifespan, and provide real-time information about its performance. BMSs are commonly used in electric vehicles, portable electronic devices, renewable energy systems, and many other applications where batteries are used.

The BMS also manages the discharging process to prevent the battery from being discharged too deeply, which can reduce its lifespan. It monitors the temperature of the battery and ensures that it does not overheat, which can be a safety hazard. In addition, the BMS can provide real-time information about the battery's performance, such as voltage, current, temperature, and SoC. This information can be used to optimize the battery's performance and to detect any problems that may arise. BMSs are commonly used in electric vehicles, portable electronic devices, renewable energy systems, and many other applications where batteries are used.



Fig 4.7: Battery Management System

4.3.6 Battery Eliminator

A battery eliminator is an electrical device that is powered by a source other than a battery and then transforms the source to an appropriate DC voltage. Battery eliminators are used in lieu of standard dry batteries to power electronics such as radio receivers AM/FM, tape recorders, computers, and other low power powered

devices. The result of a battery eliminator is a direct current voltage that typically ranges from 1.5 V / 3 V to 12 Volts / up to 500 mA.

The Battery Eliminator is designed to provide a constant and stable supply of power to the device, eliminating the need for battery replacements and reducing the cost of maintenance. It typically comes with a range of output voltages and currents to match the requirements of different electronic devices. Battery Eliminators can come in various forms, such as wall-mounted or desktop models, and can be customized to fit specific needs. They are typically easy to install and use, requiring only a simple connection to an AC power source and the device being powered.



Fig 4.8: Battery Eliminator

4.3.7 Arduino

The Arduino UNO is a low-cost, versatile, and simple-to-use programmable open-source micro controller device that can be incorporated into a wide range of electrical applications. Users can build dynamic electronic items using this open-source electronic prototyping tool. As an output, this board can operate switches, LEDs, servos, and actuators and can be interfaced with other Arduino boards, Arduino shields, and Raspberry Pi boards. The term "uno" means "one" in Italian and was selected to represent a significant redesign of the Arduino hardware and software. The Uno board was the 9th iteration in a line of USB-based Arduino boards and was the successor to the Duemilanove release. The Arduino IDE for the Arduino Uno device, version 1.0, has now developed to later versions. The boards ATmega328 is pre-programmed with a boot loader that enables new coder.

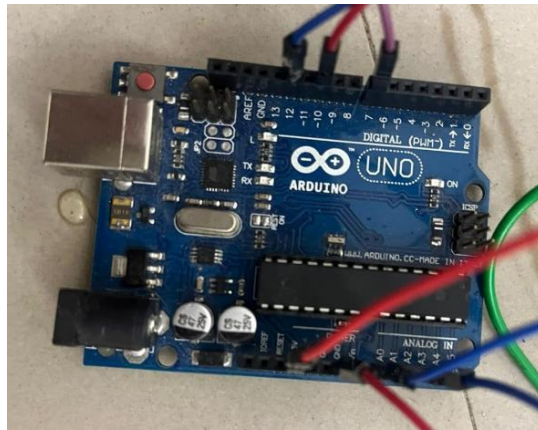


Fig 4.9: Arduino

4.3.8 Tank

Is used as the storage unit of the coolant. Storage tanks are containers designed to store and hold various types of liquids, such as water, petroleum, chemicals, and liquefied gases. They come in various sizes and shapes, including cylindrical, rectangular, and spherical, and can be made from different materials such as steel, concrete, and plastic.



Fig 4.10: Tank

4.3.9 Heating Coil

The coil in the heater conducts the electric current that turns electrical energy into thermal energy. A coil is a heating device that is connected to the heating appliance. The heater produces an electric current that flows through the coil, converting electric energy into thermal energy. It can either be immediately immersed in the material or radiate heat through an open area to heat it. A heating device uses Joule heating to turn electrical energy into heat. Electric current passing through the element meets resistance, causing the element to heat up. Unlike the Peltier effect, this mechanism is not affected by current motion. A heating coil has two primary characteristics: (1) high melting and (2) high resistance. (i) It should have a high resistance so that a large portion of the electromagnetic energy is transformed to thermal energy. (ii) It should not easily oxidise up to a temperature of 1000°C. (iii) It should have a high melting point and a low thermal expansion so that when heated, it does not become relaxed.



Fig 4.11: Heating Coil

4.3.10 Coolant

A liquid that is typically used to decrease or control the temperature of a system. An ideal coolant has a high thermal capacity, low viscosity, is low in cost, non-toxic, chemically neutral, and neither causes nor encourages cooling system to corrosion. In certain circumstances, the refrigerant must also be an electrical insulator. While the word "coolant" is widely used in car and HVAC applications, heat-transfer fluid is a technical name that is used in both high and low-temperature manufacturing applications. Cutting fluids are also included in the

definition. Water-soluble coolant and clear cutting fluid are the two main categories of industrial cutting fluid. An oil-in-water mixture is a water-soluble lubricant. It contains different amounts of oil, ranging from zero to 100%. (synthetic coolant). This coolant can either maintain its phase, remaining liquid or gaseous, or it can go through a phase change, increasing the chilling effectiveness as the latent heat is released. The latter is more frequently referred to as refrigerant when it is used to attain temperatures below ambient.



Fig 4.12: Coolant

4.3.11 One kill switch

In the context of IT, a kill switch is a method for turning off or deactivating a gadget or programme. In the context of IT, a kill switch is a method for turning off or deactivating a gadget or programme. A kill switch's main function is typically to stop data or machine theft or, in an emergency, to close down equipment. The output, process, or programme that a kill switch is meant to safeguard will determine how much it restricts, modifies, or stops a given action or activity. When it comes to the kinds of technology, programs, and tools used to develop and support it, the word "kill switch" is broad.

A kill switch, also known as a large red button, may be used in production facilities to close down equipment if a worker is in dangerous circumstances. On the other hand, kill switch software occasionally contains kill switches that are software-encoded, like anti-piracy devices. Kill switches have a wide variety of uses

because of how broadly the term is used; these uses significantly vary depending on the medium and goal. Here are some of the kill switch's more typical uses and sectors, including those related to hacking.



Fig 4.13: One kill switch

4.3.12 Battery Male Female Connector Plug

Male connectors, also known as plugs, have a solid point for the centre wire. A centre wire with a hole characterizes a female connection, also known as a jack. The female connection is always used to attach batteries. For electricity sources, this is always the accepted practise. Take into account putting a paperclip or tiny penny on the connection. That could readily short-circuit the male connection. A power cable on an appliance ends in a (male) plug; it attaches to a (female) socket in a wall or on an extension line.



Fig 4.14: Battery Male Female Connector Plug

4.3.13 Copper Sheet

Copper sheet is a highly malleable and usable metal that has excellent electrical and heat transmission. Copper and copper alloys are commonly joined using soldering, brazing, welding, fastening, riveting, crimping, and glue bonding. Plumbing connections and components are examples of typical soldering and brazing uses. Copper and copper nickel welded tubes are widely used in water supply systems, heat ex-changers, and air conditioners, and welding techniques are widely used. Copper's softness, malleability, and good formability make it suitable for building use. Other metals and copper alloys, such as brasses, phosphor bronzes, and copper nickels, are used to reinforce copper. Copper alloys with tensile properties beat some aluminium alloys, equal stainless steels, and have a broad variety of applications. Copper metals have the potential to help with the miniaturisation of electrical components. Copper is a durable material that can last for decades without losing its structural integrity or performance. It is also resistant to rust and corrosion, which makes it a popular choice for outdoor and marine applications. Copper conduit is commonly used in plumbing, whereas copper tube is used in heating and ventilation systems in homes, businesses, and industries. When compared to aluminum, copper has superior anti-corrosive qualities



Fig 4.15: Copper Sheet

4.3.14 Lithium-ion (Li-ion) battery

Lithium-ion (Li-ion) batteries are rechargeable batteries commonly used in portable electronic devices, electric vehicles, and renewable energy systems. They are popular due to their high energy density, low self-discharge rate, and relatively

long lifespan. Li-ion batteries are made up of multiple cells, each containing a positive electrode (cathode), a negative electrode (anode), and an electrolyte that separates the electrodes. When the battery is charged, lithium ions move from the cathode to the anode, and during discharge, the ions move in the opposite direction, producing an electrical current.



Fig 4.16: Lithium-ion battery

When the gadget is plugged in, the cathode releases lithium ions, which are absorbed by the anode. It is the most common form of battery used in portable consumer devices and electric vehicles. It is also widely used in grid-scale energy storage, as well as military and aircraft uses. Anode and cathode materials, which are both composed of compounds having lithium atoms, are the reactants in the electrochemical processes in a lithium-ion cell. An oxidation half-reaction at the electrode generates positively charged lithium ions and negatively charged electrons during discharge. In a reduction half-reaction, lithium ions move through the electrolyte. Electrons move through the exterior circuit, and they reunite at the cathode (along with the cathode substance). Lithium compounds such as LiPF_6 , LiBF_4 , or LiClO_4 in an organic fluid such as ethylene carbonate, dimethyl carbonate, or diethyl carbonate make up the liquid electrolytes in lithium-ion batteries. During discharge, a liquid electrolyte serves as a conductive conduit for cations to travel from the negative to positive electrodes. Typical liquid electrolyte conductivities at room temperature ($20\text{ }^\circ\text{C}$ ($68\text{ }^\circ\text{F}$)) are in the 10 mS/cm range, rising by roughly 30-40% at $40\text{ }^\circ\text{C}$ ($104\text{ }^\circ\text{F}$), and dropping marginally at $0\text{ }^\circ\text{C}$ ($32\text{ }^\circ\text{F}$).

CHAPTER – 5

RESULTS AND DISCUSSION

5.1 HEAT FLOW SIMULATION

Thermal management is a critical aspect of battery design in electric vehicles, and the cooling system plays a vital role in maintaining the battery's performance and safety. The use of liquid coolants, such as water and ethylene glycol, can be an effective solution for battery cooling. In this report, we will discuss the simulation of a battery cooling system in Solid-works using water and ethylene glycol as coolants.

The battery cooling system was modeled in Solid-works, including the battery module, cooling plate, and coolant channels. The system was designed to circulate water and ethylene glycol, which absorbs heat from the battery module and dissipates it through the cooling plate. The simulation was performed using Solid-works Flow Simulation, a computational fluid dynamics (CFD) software [44].

5.1.1 Heat flow simulation with water as coolant

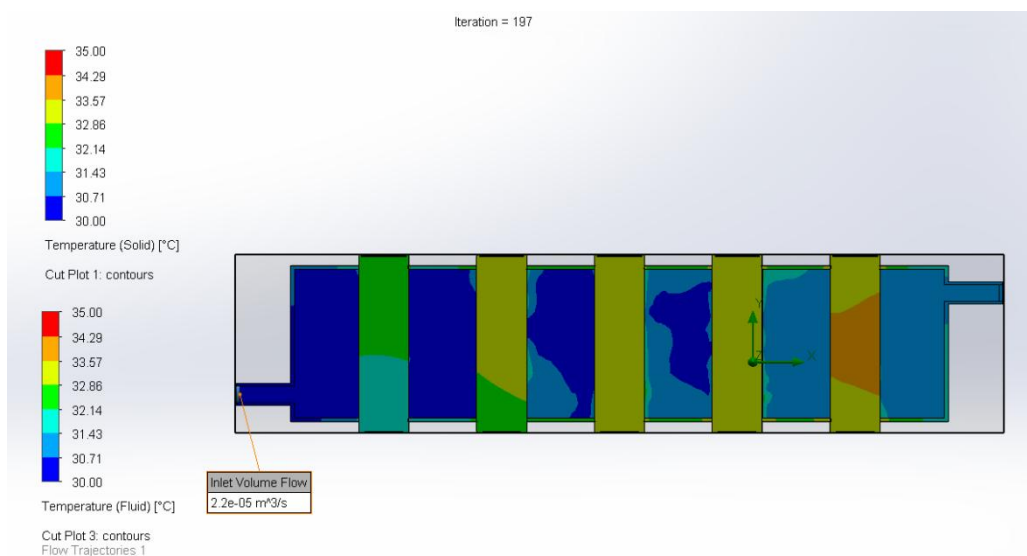


Fig 5.1: 1.32 Liter per Min inlet flow rate with 197 iteration

In this Figure it shows that the simulation for the battery cooling system with a given flow rate of 1.32 Liter per Min through the inlet with an iteration of 197. It

shows the simulation given above which happens in that cooling system with in the given range of flow rate.

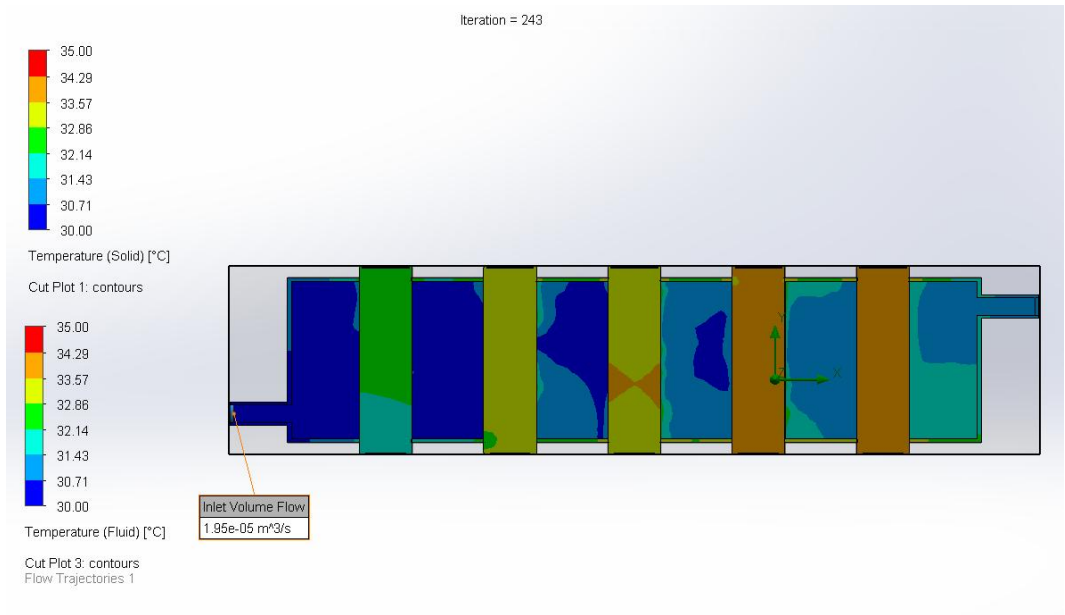


Fig 5.2: 1.17 Liter per Min inlet flow rate with 243 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 1.17 Liter per Min through the inlet with an iteration of 243. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

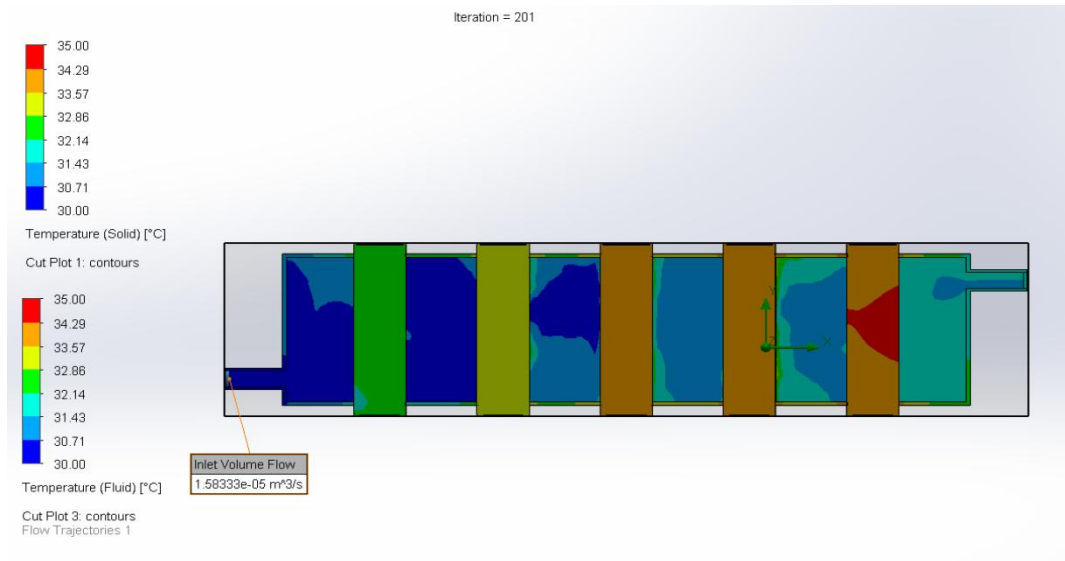


Fig 5.3: 0.95 Liter per Min inlet flow rate with 201 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 0.95 Liter per Min through the inlet with an iteration of 201. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

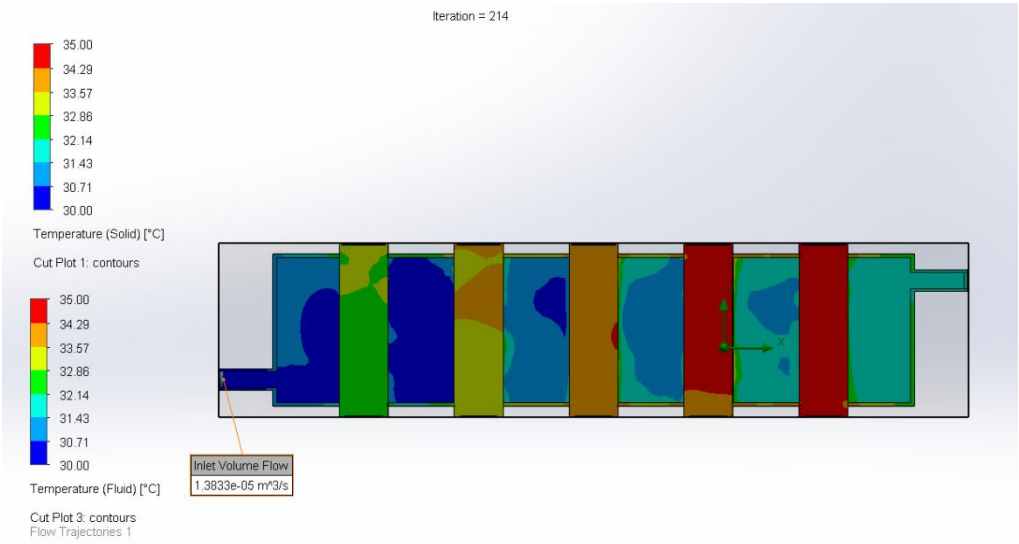


Fig 5.4: 0.83 Liter per Min inlet flow rate with 214 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 0.83 Liter per Min through the inlet with an iteration of 214. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

5.1.2 Heat flow simulation with ethylene glycol as coolant

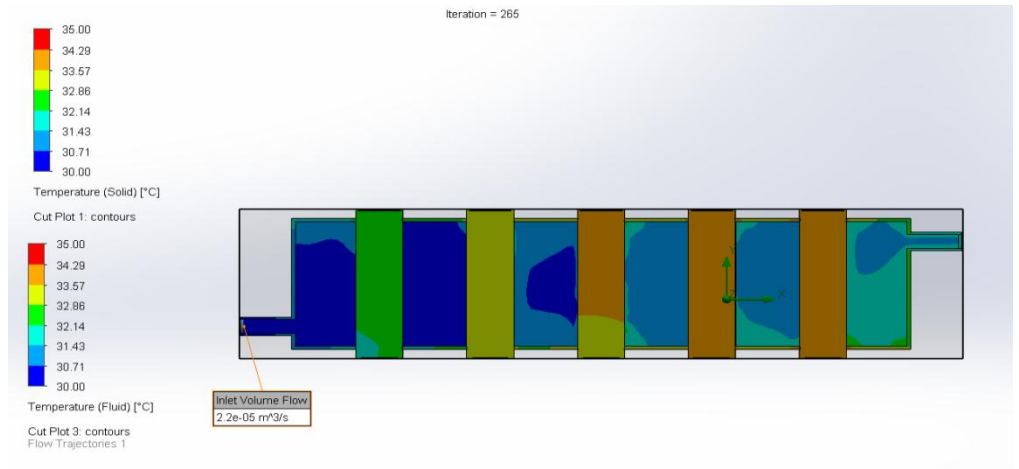


Fig 5.5: 1.32 Liter per Min inlet flow rate with 265 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 1.32 Liter per Min through the inlet with an iteration of 265. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

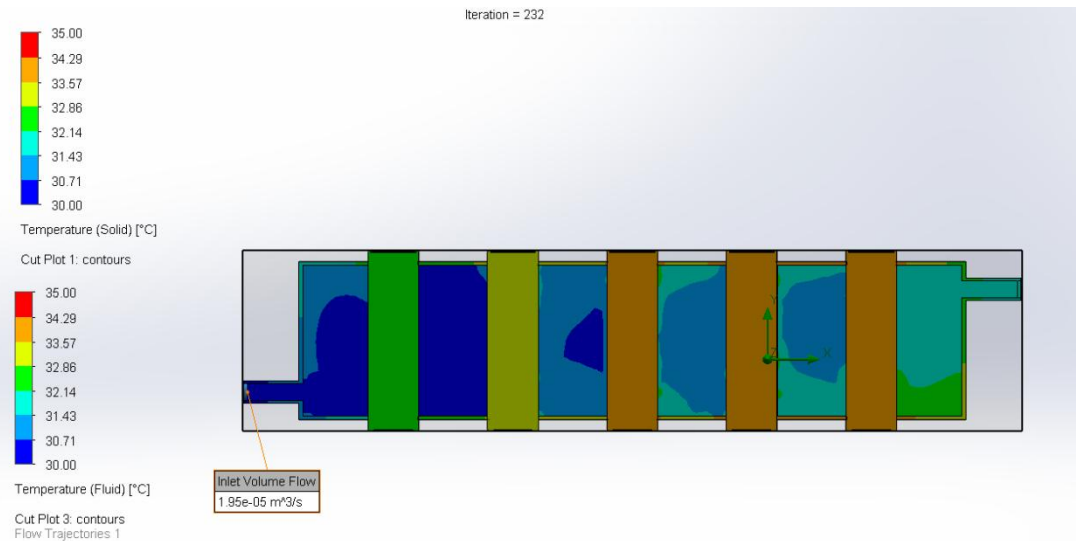


Fig 5.6: 1.17 Liter per Min inlet flow rate with 232 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 1.17 Liter per Min through the inlet with an iteration of 232. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

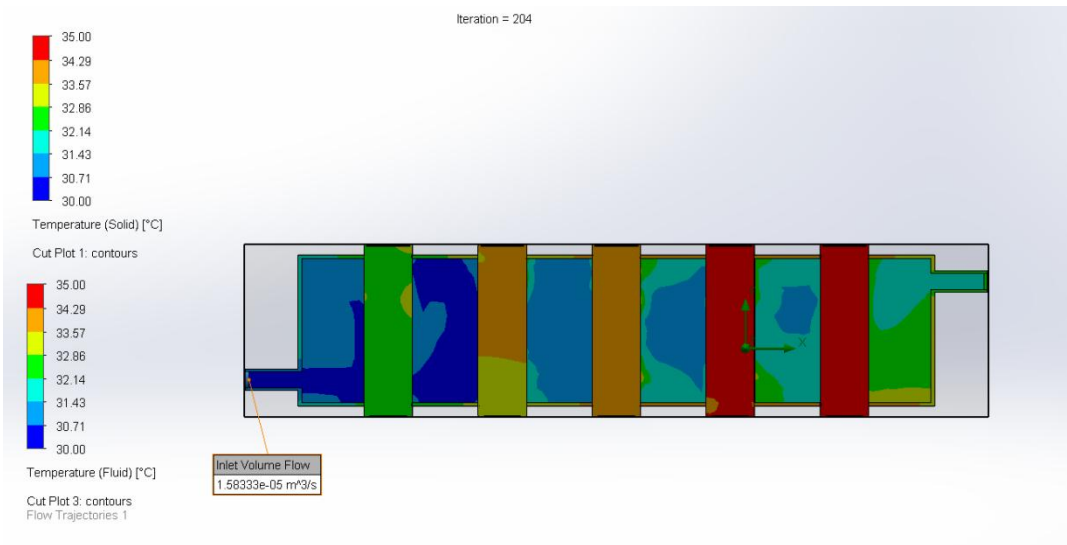


Fig 5.7: 0.95 Liter per Min inlet flow rate with 204 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 0.95 Liter per Min through the inlet with an iteration of 204. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

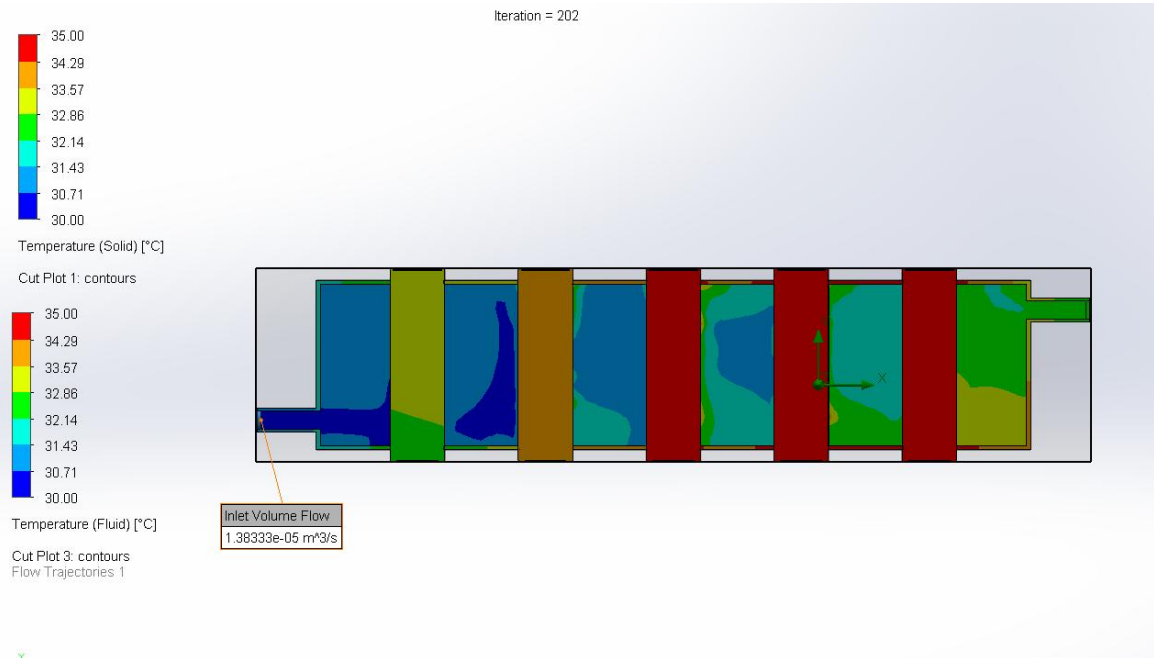


Fig 5.8: 0.83 Liter per Min inlet flow rate with 202 iteration

In this figure it shows that the simulation for the battery cooling system with a given flow rate of 0.83 Liter per Min through the inlet with an iteration of 202. It shows the simulation given above which happens in that cooling system with in the given range of flow rate.

The simulation results showed that the cooling system using water and ethylene glycol was effective in maintaining the battery module at a stable operating temperature. The coolant temperature remained within a safe range, and the heat transfer coefficient between the coolant and the cooling plate was sufficient to remove the heat generated by the battery module. Additionally, the use of ethylene glycol as a coolant increased the boiling point of the mixture, reducing the risk of coolant vaporization [45].

5.2 EXPERIMENTAL RESULTS AND DISCUSSION

5.2.1 Experimental readings with water as coolant

Table 5.1: Readings for Water

Voltage (V)	Flow Rate (mL/Min)	Temperature				Time (sec)
		Sensor-1 (S1 in °C)	Sensor-2 (S2 in °C)	Sensor-3 (S3 in °C)	Sensor-4 (S4 in °C)	
12V	1.32	33.67	60.51	60.51	36.11	0
		33.18	53.68	55.14	36.11	10.54
		32.21	49.29	50.75	36.11	19.94
		31.72	44.41	45.38	35.14	27.38
		31.72	39.53	40.02	35.14	32.73
		30.26	34.65	35.14	34.16	75.95
9V	1.17	33.67	60.02	60.51	35.14	0
		33.18	55.14	55.63	35.14	17.21
		32.70	49.29	50.26	34.16	34.83
		32.70	44.90	45.38	34.16	49.94
		32.21	39.53	40.02	34.16	82.01
		31.72	34.65	35.14	33.18	132.08
7.5V	0.95	33.67	60.02	60.51	36.11	0
		32.21	55.14	55.53	36.11	20.67
		32.21	49.29	50.26	37.09	48.95
		31.72	44.90	45.38	37.09	56.19
		31.72	39.04	40.02	36.11	104.24
		31.72	34.65	35.14	34.16	156.18
6V	0.83	32.70	60.02	60.02	36.11	0
		32.70	54.66	55.14	35.14	22.68
		32.21	48.80	50.26	34.16	52.91
		31.72	43.43	45.38	34.16	65.77
		31.72	39.04	40.02	33.18	118.74
		30.26	34.65	35.14	33.18	172.94

In this table we can easily understand the flow & thermal readings and calculations of batteries.

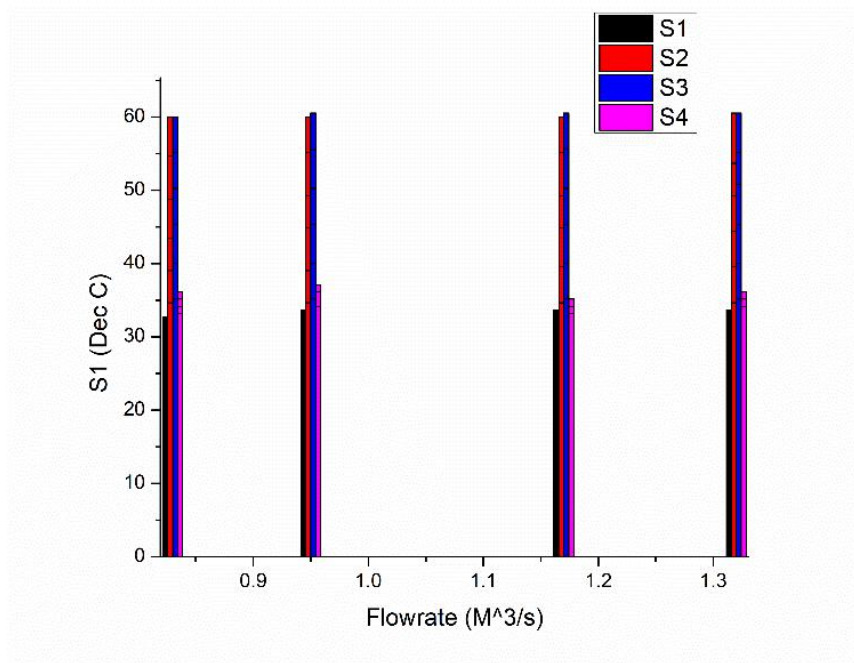


Fig 5.9: Flow rate vs Temperature for water

In this graph it shows the relation between flow rate and temperature of water. As we are passing the coolant water into the Battery cooling system with respective temperature of 12v, 9v, 7.5v and 6v it describing “Flow rate increases temperature of coolant and battery decreases”

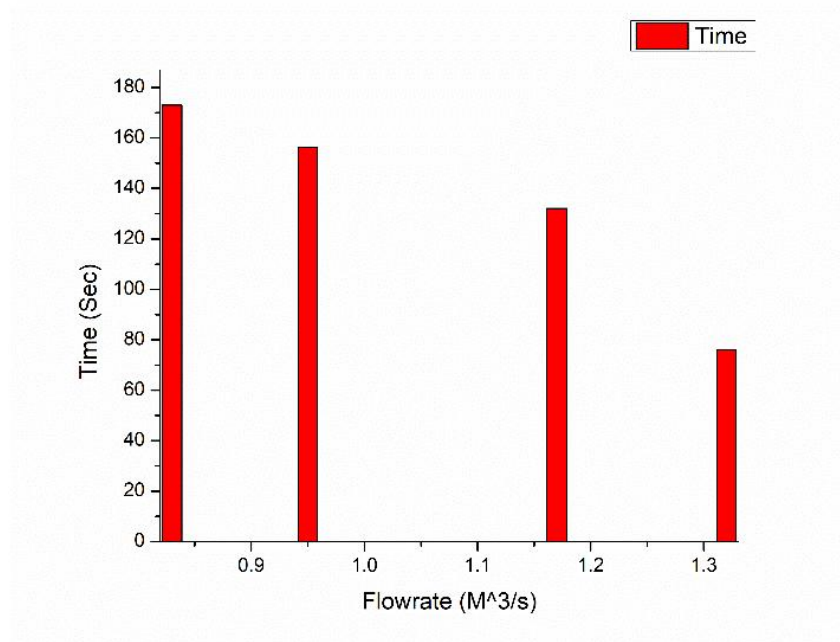


Fig 5.10: Flow rate vs Time for water

In this graph it shows the relation between flow rate and time of water. As we are passing the coolant water into the Battery cooling system with respective temperature of 12v, 9v, 7.5v and 6v it describing “ Flow rate increases time also decreases” as it gets the cooling more faster.

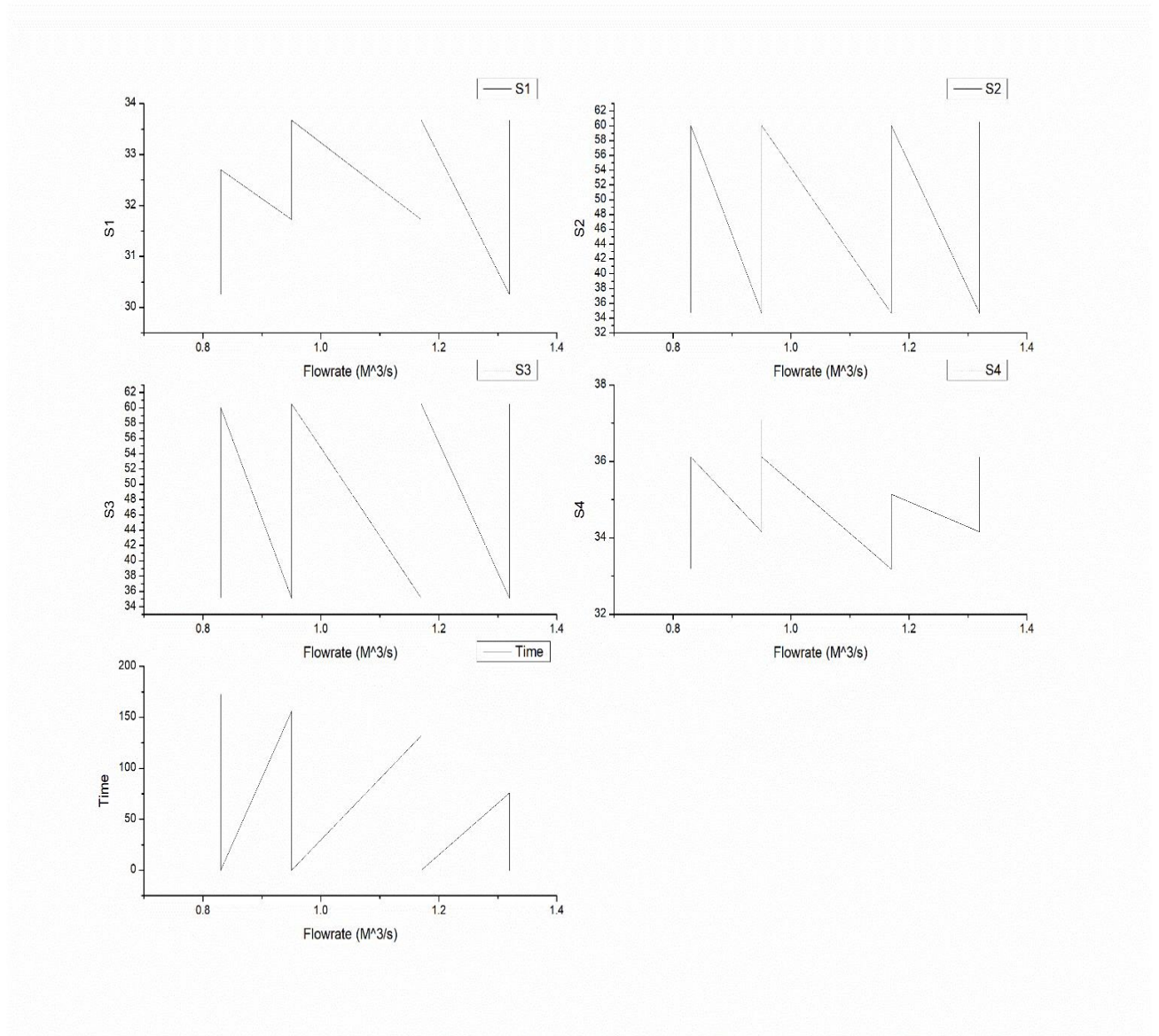


Fig 5.11: Flow rate vs Time and Temperature for water

In this experiment it shows the flow rate vs temperature of water with respective temperatures of 12v, 9v, 7.5v and 6v it describing time taken by the coolant at respective flowrates to makes the battery cool to reduce the temperature. As a “Flow rate increases the temperature decreases and time also decreases”.

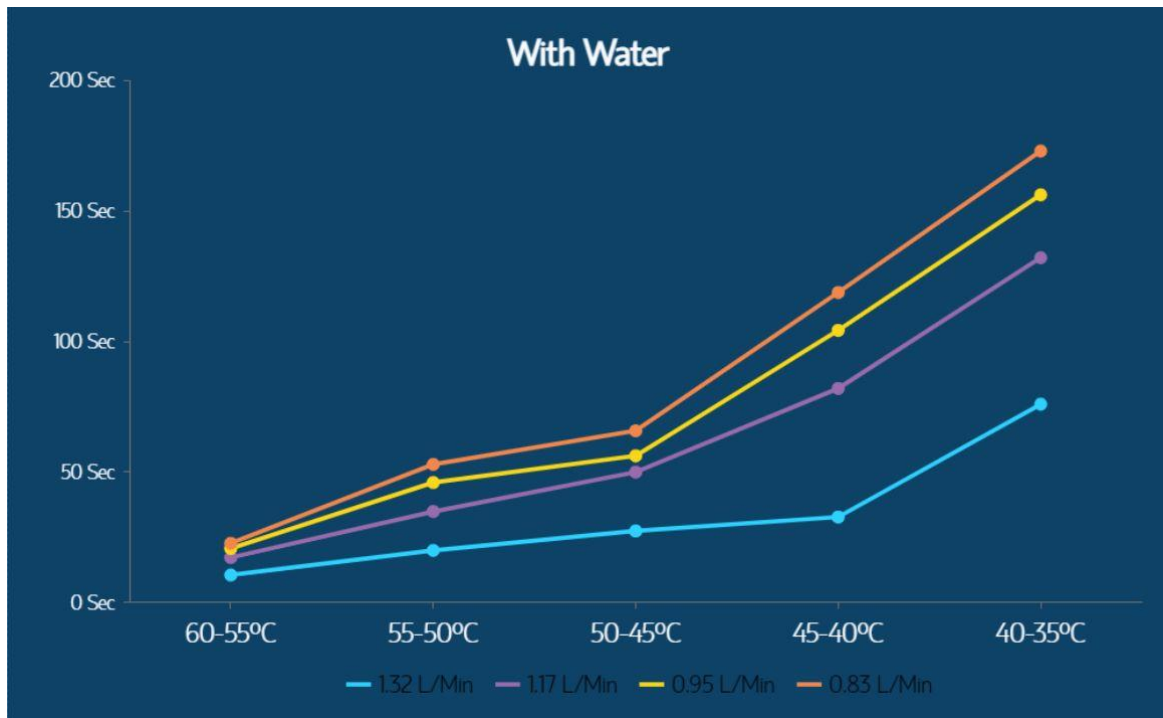


Fig 5.12: Graphical reading of temperature and time measurements with water

In this graph it shows the exact reading between the temperature and time of using Water and the cooling state of the battery as a function of time.

5.2.2 Experimental readings with ethylene glycol as coolant

Table 5.2: Readings for ethylene glycol

Voltage(V)	Flow Rate (mL /Min)	Temperature				Time (sec)
		Sensor -1 (S1 in °C)	Sensor -2 (S2 in °C)	Sensor -3 (S3 in °C)	Sensor -4 (S4 in °C)	
12V	1.32	32.21	60.02	60.51	34.16	0
		32.21	54.66	55.63	33.67	7.24
		31.72	49.29	50.26	33.67	14.23
		31.72	44.41	45.87	33.67	21.71
		31.72	39.04	40.02	32.21	32.8
		32.21	35.14	35.14	32.21	76.79
9V	1.17	32.21	60.51	60.51	35.14	0
		32.21	54.17	55.14	34.16	10.54
		32.21	49.78	50.75	34.16	16.97
		32.21	43.92	45.38	33.67	24.61
		31.72	38.06	40.02	33.67	36.18
		32.21	35.14	35.14	33.18	78.72
7.5V	0.95	33.18	60.02	60.02	35.14	0
		33.18	54.17	55.14	35.14	9.67
		33.67	48.31	50.26	35.14	16.11
		33.18	44.90	45.38	35.62	23.1
		33.18	38.06	40.02	35.14	35.23
		32.70	34.65	35.14	33.67	91.55
6V	0.83	33.18	60.51	60.51	34.65	0
		33.18	51.73	55.14	33.67	11.88
		33.18	45.38	50.26	33.67	19.59
		33.67	41.97	45.87	34.65	27.35
		32.70	38.55	40.02	33.67	39.66
		32.70	35.14	35.14	33.18	133.79

In this table we can easily understand the flow & thermal readings and calculations

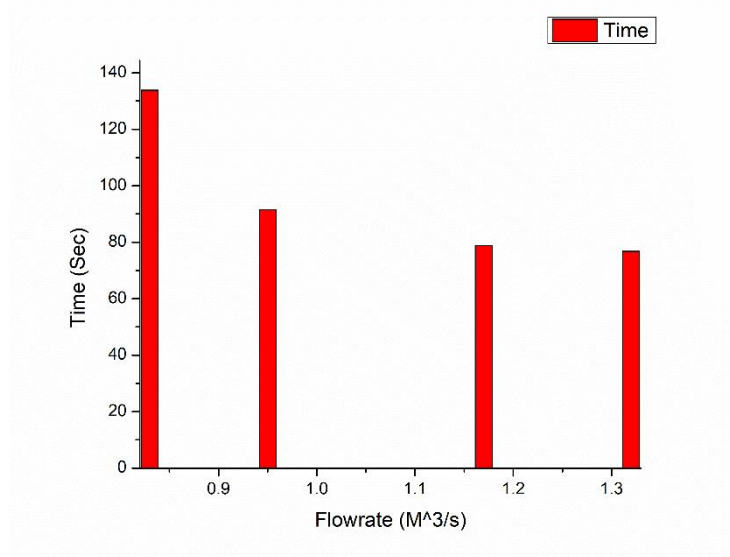


Fig 5.13: Flow rate vs Time for Ethylene glycol

In this graph it describes about the flow rate of the Ethylene glycol coolant in the respective temperatures of 12v, 9v, 7.5v and 6v it describing time taken by the coolant at respective flowrates to makes the battery cool

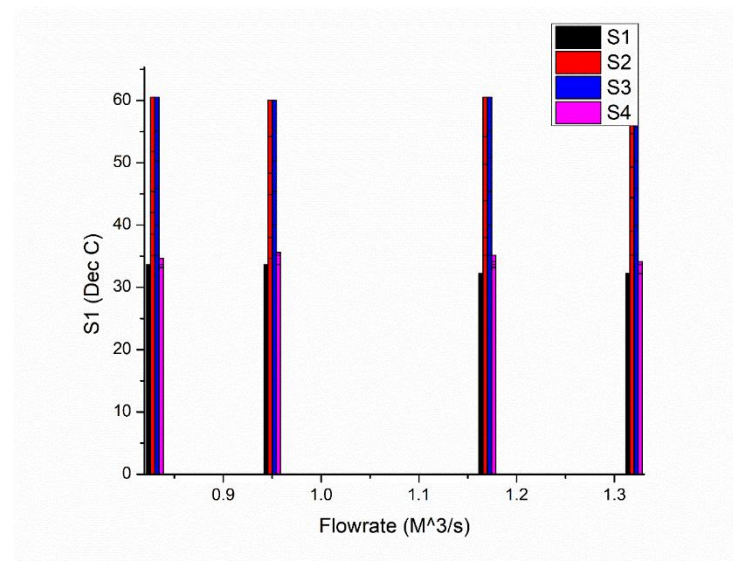


Fig 5.14: Flow rate vs Temperature for Ethylene glycol

In this experiment it shows the flow rate and temperature of the Ethylene glycol coolant with respective temperatures of 12v, 9v, 7.5v and 6v it describing time taken by the coolant at respective flow rates to makes the battery cool to reduce the temperature. As a flow rate increases the temperature decreases.

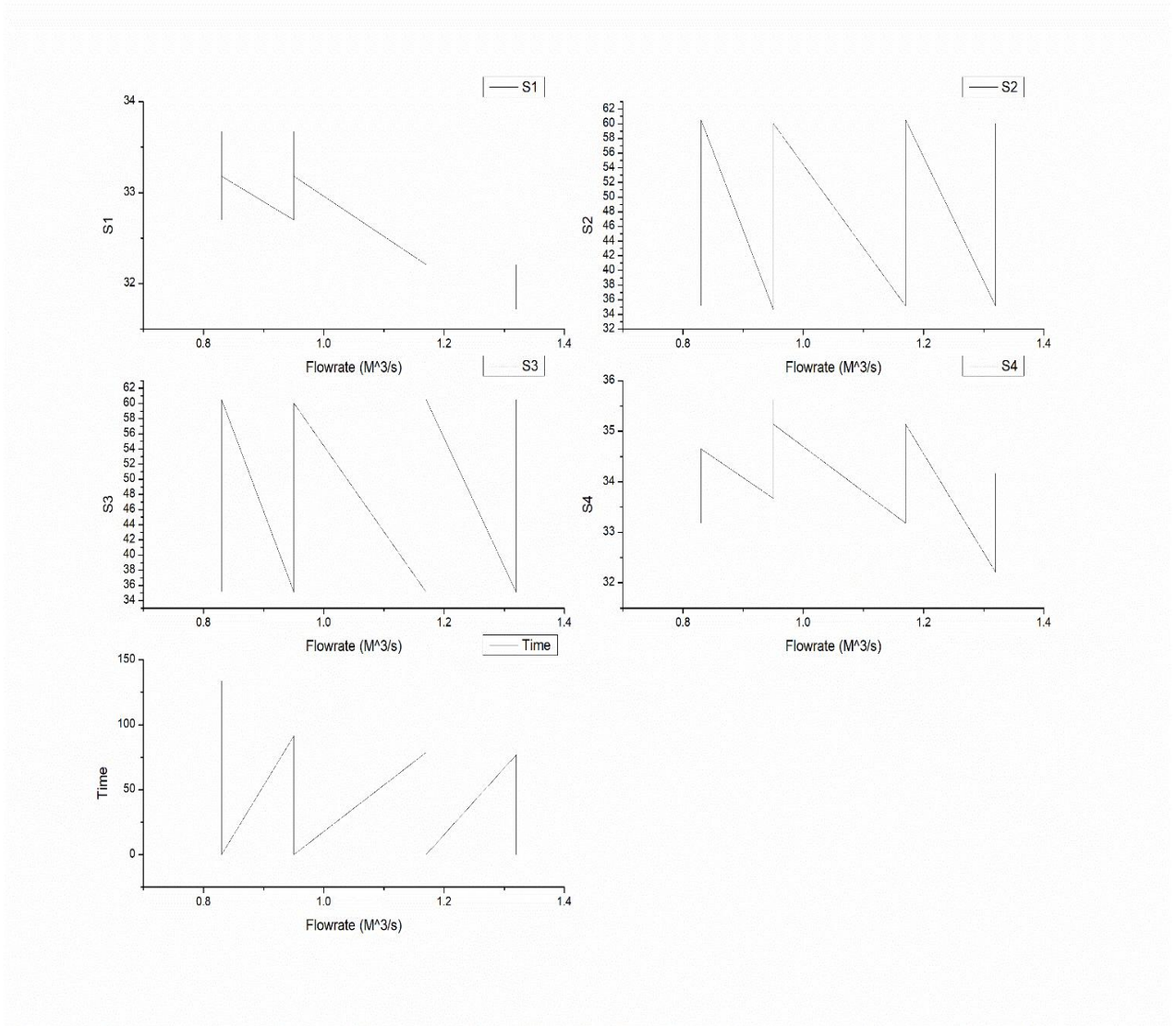


Fig 5.15: Flow rate vs Time and Temperature for Ethylene glycol

In this experiment it shows the flow rate vs time taken and temperature of the ethylene glycol coolant with respective temperatures of 12v, 9v, 7.5v and 6v it describing time taken by the coolant at respective flow rates to makes the battery cool to reduce the temperature. As a flow rate increases the temperature decreases and time also decrease.

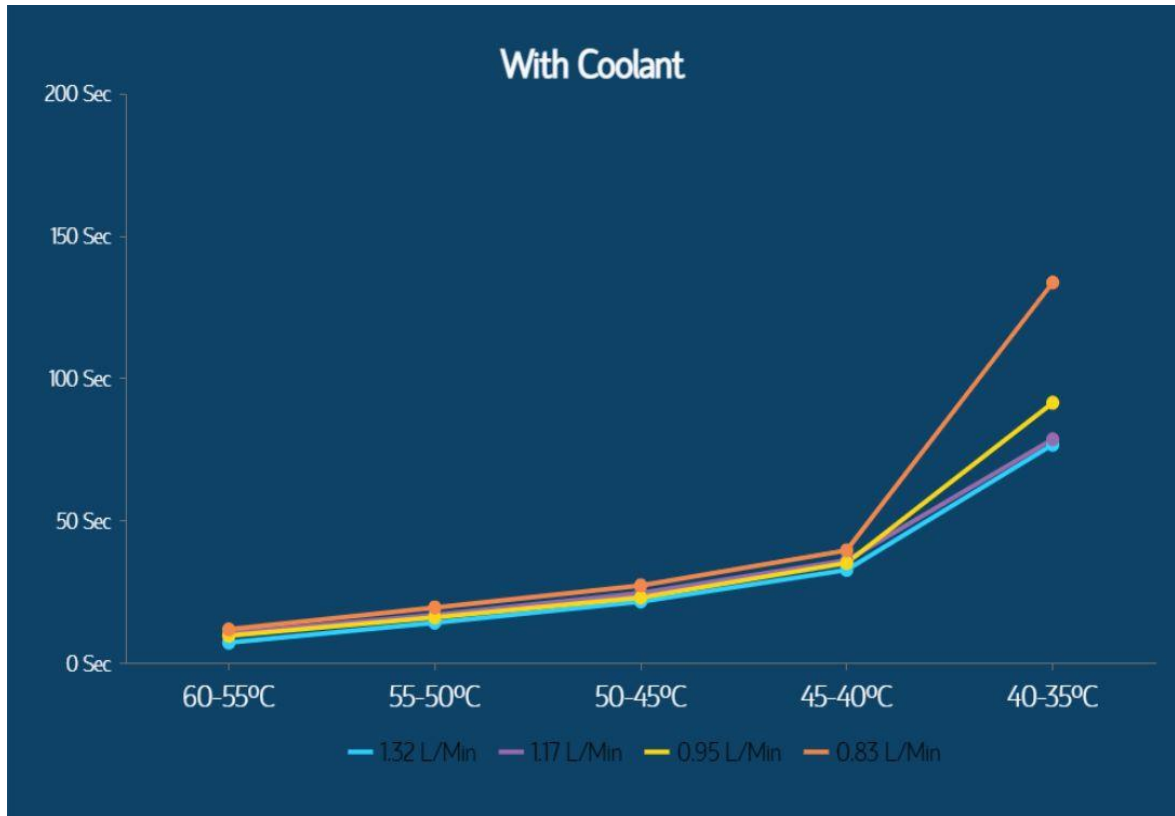


Fig 5.16: Graphical reading of temperature and time measurements with ethylene glycol

In this graph it shows the exact reading between the temperature and time of using Ethylene Glycol and the cooling state of the battery as a function of time.

Now the tables below show the temperature and flow readings of the battery. The temperature of 4 sensors placed in the experiment with the time required to return to the normal state. With two coolants Water and Ethylene Glycol as in the tables below with voltages 12v, 9v, 7.5v and 6v. with the help of this we can determine the cooling state of the battery.

CHAPTER – 6

SUMMARY AND CONCLUSION

This method is used to fix problems that arise in the Li-ion batteries of electric vehicles. Through this method, we can cool Li-ion batteries and help them improve their life cycle. This is very useful for electric vehicles because we can reduce the risk of death which are occurring due to the explosion of batteries. Ultimately, we expect the battery cooling system to make electric vehicles safer and risk-free. So in this experiment we realized a battery cooling system by which we can control the battery from thermal overload and prevent the battery from exploding due to overheating. This experience helps to control the overheating process to keep the battery stable by the continuous flow of coolant and we can bring the battery temperature to normal room temperature in a short time. We got the expected output of cooling technology of the battery to rescue from overheating [46]. The efficiency of the battery increases in this process. Compared with other methods, this method gives accurate results and low cost, we can control the battery from exploding due to overheating. This is the biggest and most common problem that occurs frequently in daily life. This configuration is very useful and helps to know about the life cycles of the batteries. In this experiment, the advantage is inexpensive, frequent and accurate readings occurred. Compared to other works this work makes more impact on the battery cooling technology [47].

The following details are also fascinating in addition to the two issues mentioned above:

The battery behaviour before and after driving, along with the accompanying thermal treatment, or pre- and post-condition, should be further researched as a possible source of energy savings, according to BTMS. According to various conditions, several control strategies can be established. Energy use for cooling and heating will change and maybe be reduced [48].

More stricter thermal requirements are needed because the battery pack will produce a lot of heat when it is charging. To achieve both safety and a high charging rate, it is strongly advised that a proper control strategy for BTMS charging be developed.

In general, this thesis has examined how the battery, which is charged by a control unit, is using more energy while its intended temperature is dropping. However, there are other elements that have an impact on BTMS's energy usage, such as the switching differential of the control relays for the air conditioner and radiator [49].

This thesis viewed the battery as a single, homogeneous body. Despite the fact that battery cells actually have a varied distribution of temperature, each place on the battery had the same temperature at all times. This is interesting to measure. Redesigning the BTMS to smooth out the unevenness is also intriguing.

Assessment of BTMS energy consumption is dependent on a variety of circumstances rather than just one specific circumstance. For a thorough review, for instance, both the frigid winter and the hot summer weather should be considered [50]. It seems sense to create these simulation circumstances with variable factors, such as the average city temperature throughout the year, charging behaviour, and BTMS ageing. This comprehensive analysis would show BTMS's performance in a more usable way.

References

- [1] A.Alrashdan, A.T. Mayyas, S. Al-Hallaj Thermo-mechanical behaviors of the expanded graphite-phase change material matrix used for thermal management of Li-ion battery packs J. Mater. Process. Technol., 210 (1) (2010), pp. 174-179, [10.1016/j.jmatprotec.2009.07.011](https://doi.org/10.1016/j.jmatprotec.2009.07.011).
- [2] A.A.Pesaran, "Battery thermal management in EVs and HEVs: issues and solutions," in proceedings of the advanced automotive battery conference, Las Vegas, Nev, USA, February 2001.
- [3] Ali, M.U.; Zafar, A.; Nengroo, S.H.; Hussain, S.; Junaid Alvi, M.; Kim, H.-J. Towards a smarter battery management system for electric vehicle applications: A critical review of lithium-ion battery state of charge estimation. Energies 2019, 12, 446. <https://www.mdpi.com/1996-1073/12/3/446>.
- [4] Aneke, M., Wang, M.: Energy storage technologies and real life applications – A state of the art review. Applied Energy. 179, 350-377 (2016). <https://doi.org/10.1016/j.apenergy.2016.06.097>.
- [5] Basu, S., Hariharan, KS., Kolake, SM., Song, T., Sohn, DK., Yeo, T.: Coupled electrochemical thermal modelling of a novel Li-ion battery pack thermal management system. Applied Energy. 181, 1-13 (2016). <https://doi.org/10.1016/j.apenergy.2016.08.049>.
- [6] Brumley, Justin A., "A Study of the Energy Consumption of a Battery Cooling System by Different Cooling Strategies" (2016). Graduate Theses, Dissertations, and Problem Reports. 5273. <https://researchrepository.wvu.edu/etd/5273>.
- [7] Burgers, J., Jalili, M., Machler, M., and Strauss, R., "Automotive Coolant Inhibitor Protection of an EV Cooling System Having Copper and Aluminum Heat Exchangers,"SAE Technical Paper 2021-01-0227, 2021, <https://doi.org/10.4271/2021-01-0227>.
- [8] C. Zhao., W. Cao., T. Dong., F. Jiang.: Thermal behavior study of discharging/charging cylindrical lithium-ion battery module cooled by channeled liquid flow, Int. J. Heat Mass Tran. 120, 751–762 (2018). <https://doi.org/10.1016/j.ijheatmasstransfer.2017.12.083>.

- [9] Cherkashinin, Gennady., Hausbrand, René., Jaegermann, Wolfram.: Performance of Li-Ion Batteries: Contribution of Electronic Factors to the Battery Voltage. *Journal of The Electrochemical Society*, 166(3), A5308–A5312 (2019).<https://doi.org/10.1149/2.0441903jes>.
- [10] Di Domenico, D.; Fiengo, G.; Stefanopoulou, A. Lithium-ion battery state of charge estimation with a kalman filter based on a electrochemical model. In Antonio, TX, USA, 3–5 September 2008.
- [11] F.-L. Yun, L. Tang, W.-C. Li, W.-R. Jin, J. Pang, S.-G. Lu, Thermal behavior analysis of a pouch type Li [Ni 0.7 Co 0.15 Mn 0.15] O 2-based lithium-ion battery, *Rare Met.* 35, 309–319 (2016).
- [12] F. Leng, C.M. Tan, M. Pecht Effect of temperature on the aging rate of Li ion battery operating above room temperature *Sci. Rep.*, 5 (1) (2015), pp. 1-12.
- [13] Gao, Tianyi., Tang, Hu., Cui, Yan., Luo, Zhiming.: A test study of technology cooling loop in a liquid cooling system. *IEEE 2018 17th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems(ITherm)-SanDiego,CA, USA*, pp. 740-747 (2018),
<https://doi.org/10.1109/ITHERM.2018.8419519>.
- [14] Huang, C-K., Sakamoto, JS., Wolfenstine, J., Surampudi, S.: The limits of low temperature performance of Li-ion cells. *Journal of The Electrochemical Society*. 17(8), 2893-2896 (2000).<https://doi.org/10.1149/1.1393622>.
- [15] Huiming Zou, Bin Jiang, Qian Wang, Changqin Tian, Yuying Yan, Performance analysis of a heat pump air conditioning system coupling with battery cooling for electric vehicles.
- [16] Hunt, Ian A., Zhao, Yan., Patel, Yatish., Offer, J.: Surface Cooling Causes Accelerated Degradation Compared to Tab Cooling for Lithium-Ion Pouch Cells. *Journal of The Electrochemical Society*. 163(9), A1846–A1852 (2016).
<https://doi.org/10.1149/2.0361609jes>.
- [17] J. Kim., J. Oh., H. Lee.: Review on Battery Thermal Management System for Electric Vehicles. *Applied Thermal Engineering* (2018).
<https://doi.org/10.1016/j.applthermaleng.2018.12.020>.

- [18] Jaguemont, J., Boulon, L., Dubé, Y.: A comprehensive review of lithium-ion batteries used in hybrid and electric vehicles at cold temperatures. *Applied Energy*. 164, 99-114 (2016).<https://doi.org/10.1016/j.apenergy.2015.11.034>.
- [19] Jaidi, J., Chitta, S.D., Akkaldevi, C., Panchal, S., Fowler, M., Fraser, R.: Performance Study on the Effect of Coolant Inlet Conditions for a 20 Ah LiFePO₄ Prismatic Battery with Commercial Mini Channel Cold Plates. *Electrochem*. 3, 259–275 (2022).<https://doi.org/10.3390/electrochem3020018>.
- [20] Joshua, Smith., Singh, Randeep., Hinterberger, Michael., Mochizuki, Masataka.: The Battery thermal management system for electric vehicle using heat pipes. *International Journal of Thermal Sciences*. 134, 517-529 (2018).
<https://doi.org/10.1016/j.ijthermalsci.2018.08.022>.
- [21] Kimulu, Ancent., Mutuku, Winfred., Mutua, Nicholas.: Car Antifreeze and Coolant: Comparing Water and Ethylene Glycol as Nano Fluid Base Fluid. *International Journal of Advances in Scientific Research and Engineering*. 4, 17-37 (2018).<https://doi.org/10.31695/IJASRE.2018.32748>.
- [22] K. Li, J. Yan, H. Chen, Q. Wang, water cooling based strategy for lithium ion battery pack dynamic cycling for thermal management system, *applied thermal engineering* 2017.
- [23] Lu, L.; Han, X.; Li, J.; Hua, J.; Ouyang, M. A review on the key issues for lithium-ion battery management in electric vehicles. *J. Power Sources* 2013, 226, 272-288.
- [24] Ma, Shuai., Jiang, Modi., Tao, Peng., Song, Chengyi., Wu, Jianbo., Wang, Jun., Deng, Tao., Shang, Wen.: Temperature effect and thermal impact in lithium-ion batteries: A review. *Progress in Natural Science: Materials International* (2018).<https://doi.org/10.1016/j.pnsc.2018.11.002>.
- [25] Marin Montanari, Pedro., Hummes, Diego., Hunt, Julian., Hervé, Bruno., Schneider, Paulo.: A Comparative Study of Different Battery Geometries Used in Electric Vehicles. *SSRN Electronic Journal*. 1. 1 (2022).
<http://dx.doi.org/10.2139/ssrn.4084408>.

- [26] Nazari A, Farhad S. Heat generation in lithium-ion batteries with different nominal capacities and chemistries. *Applied Thermal Engineering*, 2017, 125: 1501-1517.
- [27] Ng, K.S.; Moo, C.S.; Chen, Y.P.; Hsieh, Y.C. Enhanced coulomb counting method for estimating state-of-charge and state-of-health of lithium-ion batteries. *Appl. Energy* 2009, 86, 1506–1511.
- [28] Nitta, N., Wu, F., Lee, J.T., Yushin, G.: Li ion Battery Materials: Present and Future. *Materials Today* . 18(5), 252-264 (2014).
<https://doi.org/10.1016/j.mattod.2014.10.040>.
- [29] Olabi, A.; Wilberforce, T.; Sayed, E.T.; Abo-Khalil, A.G.; Maghrabie, H.M.; Elsaid, K.; Abdelkareem, M.A. Battery energy storage systems and SWOT (strengths, weakness, opportunities, and threats) analysis of batteries in power transmission. *Energy* 2022, 254, 123987. <https://www.sciencedirect.com/science/article/abs/pii/S0360544222008908?via%3Dihub>.
- [30] P. Goli, S. Legedza, A. Dhar, R. Salgado, J. Renteria, A.A. Balandin Graphene-enhanced hybrid phase change materials for thermal management of Li-ion batteries *J. Power Sources*, 248(2014), pp.37-43, 10.1016/j.jpowsour.2013.08.135.
- [31] Qian, S.T. The Design of Heat Radiation Structure and Simulation of Cooling System for EV'S Li-ion Power Battery. Master's Thesis Zhejiang University of Technology, Hangzhou, China, 2013.
- [32] Rodrigues, M.T.F.; Babu, G.; Gullapalli, H.; Kalaga, K.; Sayed, F.N.; Kato, K.; Joyner, J.; Ajayan, P.M. A materials perspective on Li-ion batteries at extreme temperature. *Nat. Energy* 2017, 2, 17108.
<https://www.nature.com/articles/nenergy2017108>
- [33] S.M. Peyghambarzadeh., S.H. Hashemabadi., S.M. Hoseini., M. Seifi Jamnani.: Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators. *International Communications in Heat and Mass Transfer*. 38(9), 1283–1290 (2011). <https://doi.org/10.1016/j.icheatmasstransfer.2011.07.001>.
- [34] Shahjalal, M., Shams, T., Islam, M. E., Alam, W., Modak, M., Hossain, S. B., Ramadesigan, V., Ahmed, M. R., Ahmed, H., & Iqbal, A.: A review of thermal

- management for Li-ion batteries: Prospects, challenges, and issues. *Journal of Energy Storage*. 39, 102518 (2021).<https://doi.org/10.1016/j.est.2021.102518>.
- [35] Shang, Z., Qi, H., Liu, X., Ouyang, C., and Wang, Y.: Structural Optimization of Lithium-Ion Battery for Improving Thermal Performance Based on a Liquid Cooling System, *Int. J. Heat Mass Transf.*, vol. 130, pp. 33-41 (2019).
- [36] Studocu. com/en -za/ document/ university-of-the-wit watersrand johannesburg /physics/heat-conductivity-of-metals/35301097.
- [37] Sun, Q.-Z., Kim, C.-H.: Effect of the Size and Location of Liquid Cooling System on the Performance of Square-Shaped Li-Ion Battery Modules of an Electric Vehicle. *Fluids*. 7, 219 (2022).<https://doi.org/10.3390/fluids7070219>.
- [38] T. Waldmann., R.-G. Scurtu., K. Richter., M. Wohlfahrt-Mehrens.: 18650 vs. 21700 Li-ion cells—A direct comparison of electrochemical, thermal, and geometrical properties. *J. Power Source*. 472, 228614 (2020).
<https://doi.org/10.1016/j.jpowsour.2020.228614>.
- [39] Tarascon , JM., Armand, M.: Issues and challenges facing rechargeable lithium batteries. *Nature*. 414, 359-367 (2001).<https://doi.org/10.1038/35104644>.
- [40] Taufiq, A J., Kurniawan, I H., Nugraha, T A Y.: Analysis of Arduino Uno Application on Control System Based on Industrial Scale. *IOP Conference Series: Materials Science and Engineering*, 771, 012015 (2020).
<https://doi.org/10.1088/1757-899X/771/1/012015>.
- [41] V Karkuzhali., P Rangarajan., V Tamilselvi., P Kavitha.: Analysis of battery management system issues in electric vehicles. *IOP Conference Series: Materials Science and Engineering* (2020).<https://doi.org/10.1088/1757-899x/994/1/012013>.
- [42] Wang, Peng., Yuan, Yonghui., Xu, Ke., Zhong, Hongshan., Yang, Yinghui., Jin, Shiyu., Yang, Ke., Qi, Xun.: Biological applications of copper-containing materials. *Bioactive Materials*. 6(4), 916–927 (2021).
<https://doi.org/10.1016/j.bioactmat.2020.09.017>.
- [43] Wang, X.M.; Xie, Y.Q.; Day, R.; Wu, H.W.; Hu, Z.L.; Zhu, J.Q.; Wen, D.S. Performance analysis of a novel thermal management system with composite phase material for a lithium-ion battery pack. *Energy* 2018, 156, 154–168.

- [44] W. Wu, et al. An experimental study of thermal management system using copper mesh-enhanced composite phase change materials for power battery pack *Energy*, 113 (2016), pp. 909-916, 10.1016/j.energy.2016.07.119.
- [45] X. Luo, et al. Experimental investigation on a novel phase change material composites coupled with graphite film used for thermal management of lithium-ion batteries *Renew. Energy*, 145 (2020), pp. 2046-2055, 10.1016/j.renene.2019.07.112.
- [46] YAMADA, Tatsuya., KOSHIYAMA, Takafumi., YOSHIKAWA, Manabu., YAMADA, Takashi., ONO, Naoki.: Analysis of a lithium-ion battery cooling system for electric vehicles using a phase-change material and heat pipes. *Journal of Thermal Science and Technology*. 12(1), JTST0011-JTST0011 (2017). <https://doi.org/10.1299/jtst.2017jtst0011>.
- [47] Yue, Q.L., He, C.X., Jiang, H.R., Wu, M.C., Zhao, T.S.: A hybrid battery thermal management system for electric vehicles under dynamic working conditions. *International Journal of Heat and Mass Transfer*. 164, 120528 (2021). <https://doi.org/10.1016/j.ijheatmasstransfer.2020.120528>.
- [48] Y. Zhao, B. Zou, J. Ding, Y. Ding Experimental and numerical investigation of a hybrid battery thermal management system based on copper foam-paraffin composite phase change material and liquid cooling *Appl. Therm. Eng.* 218 (2023), Article 119312, 10.1016/j.applthermaleng.2022.119312.
- [49] Zhang, X., Kong, X., Li, G., Li, J.: Thermodynamic assessment of active cooling/heating methods for lithium-ion batteries of electric vehicles in extreme conditions. *Energy*. 64, 1092-1101, (2014). <https://doi.org/10.1016/j.energy.2013.10.088>.
- [50] Zhonghao, Rao., Shuangfeng, Wang.: A review of power battery thermal energy management. *Renewable and Sustainable Energy Reviews* (2011). <https://doi.org/10.1016/j.rser.2011.07.096>.

ANNEXURE:

- Communicated the 1st research paper titled “After Explosion - Battery Degradation Analysis using DSC and SEM” for International conference on Biotechnology for Sustainable Bioresources and Bioeconomy (BSBB-2022),Guwahati, on 21st November 2022.
- Presented the 1st research paper in International conference on Biotechnology for Sustainable Bioresources and Bioeconomy (BSBB-2022) on 9th December 2022 which is happened at IIT GUWAHATI Campus.
- Submitted the 1st research paper “After Explosion - Battery Degradation Analysis using DSC and SEM ” in “ Sustainable Chemical Engineering ” through BSBB 2022 on 27 January 2023.
- Received the reviewer comments on 21st March 2023.
- 1st paper under scrutiny for Journal publication.
- Submitted the 2nd research paper “Design and Fabrication of Li-ion battery cooling system for reducing Thermal Overloading” in “MRS Energy and Sustainability”.