Battery Thermal Management System in Electric Two-Wheelers

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Abstract

This work documents the design of a battery thermal management system for an electric vehicle in which a liquid cooling system was designed for a 24V Li-ion battery pack. Then, a thermal simulation was performed by using one-dimensional heat transfer modelling using Solidworks. This model also consists of the design of a heater, pump and evaporator to determine the total energy consumption of BTMS. The results indicate that the battery temperature is maintained between 20-30 $°C$ for various driving profiles with a maximum energy consumption of 0.3%.

Keywords: Lithium-ion cells, 18650 cells, BTMS, liquid cooling, temperature

1. Introduction

1.1 Lithium-ion Battery

A lithium-ion battery consists of an anode, cathode, electrolyte, and a division. The anode is the oxidised electrode which removes electrons from the external circuit during discharging. Similarly, the cathode is the oxidising electrode that receives electrons from the external circuit. The electrolyte is the medium to transfer ions between electrodes inside the cell and the division is used to insulate electrodes. Also, the solid electrolyte interface (SEI) is a thin passivation subcaste which is formed on the face of the carbon anode during the first charge. It slows down the response rate and decreases the current.

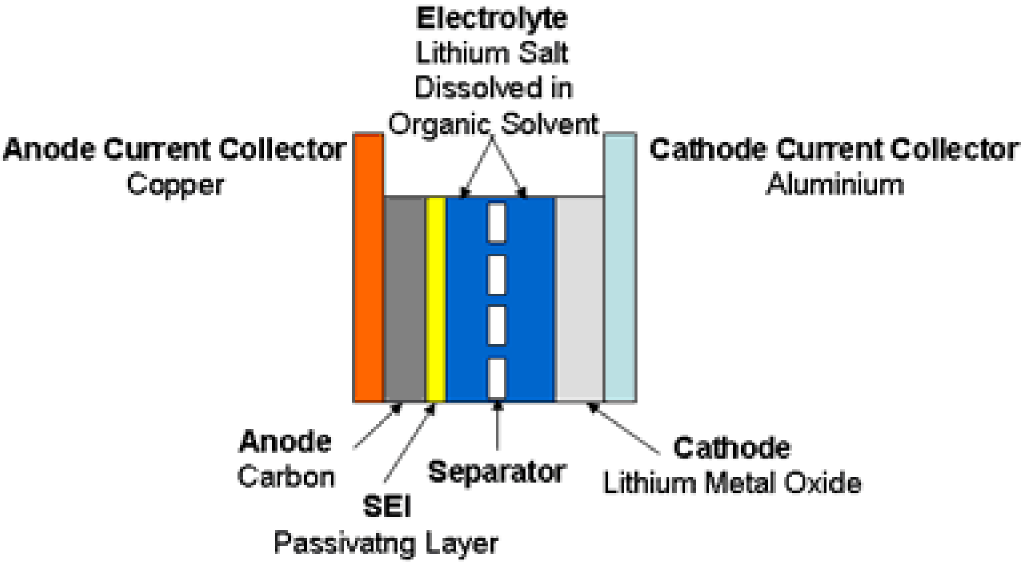


Fig 1.1 Schematic illustrations of cell

Secondly a Li- ion battery is rechargeable which means its electrochemical responses are reversible. Lithium ions disperse from the negative to the positive when discharging and go in rear when charging. Lithium- ion battery use fitted lithium emulsion as the electrode rather of metallic lithium. The electrochemical responses for Li- cobalt in the positive electrode and negative electrode are expressed as following the positive electrode response is
$\mathrm{Li}COO_2 \Leftrightarrow Li_{1-x}COO_2 + xLi^{+} + xe^{-}$

The negative electrode reaction:

$\mathrm{x}Li^{+} + xe^{-} + xC_6 \Leftrightarrow xLiC_6$

The electrochemical reactions in the positive electrode and negative electrode for other lithium batteries are similar.

Chemical name	Material	Short form	Note
Lithium Cobalt Oxide	$LiCoO_2$	Li- cobalt	High capacity; for cell phone laptop, camera
Lithium Manganese Oxide	$LiMn_2O_4$	Li- manganese	Most safe; lower capacity than Li-cobalt but high specific power and long life. Power tools, e-bikes, EV, medical, hobbyist.
Lithium Iron Phosphate	$LiFePO_4$	Li- phosphate	
Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$	NMC	
Lithium Nickel Cobalt Aluminium Oxide	$LiNiCoAlO_2$	NCA	Gaining importance in electric powertrain and grid storage
Lithium titanate	$Li_4Ti_5O_{12}$	Li-titanate	

three types of lithium batteries are particularly suitable for an EV battery, namely $LiMn_2O_4$, $LiFePO_4$, and $LiNiMnCoO_2$.

Thermal Issues of Li-ion battery

Lithium- ion cells performance depends on both the temperature and the operating voltage. Lithium- Ion cells work well when cells operate within limited voltage and temperature. Else, damage will do to the cells and will be unrecoverable. Inover-voltage situations the charging voltage exceeds the sufferable cell voltage, performing in inordinate current overflows and at the same time, it causes two problems. At inordinate currents the Lithium- ions are deposited more fleetly than intercalation to the anode layers, Lithium ions are also deposited on the face of the anode as metallic Lithium. This is Lithium plating. It gives rise to the reduction in the free Lithium ions and an unrecoverable capacity loss. There are two types of essence lithium plating, vicelike homogeneous lithium plating and miscellaneous lithium plating, but the lithium plating is dendritic in form. Ultimately it can affect in a short- circuit between the electrodes. As with over-voltage, under- voltage also brings about problems which give rise to the breakdown of the electrode accoutrements. For the anode, the bobby current collector breaks down. It causes the increase of battery discharge rate and battery voltage, still, the ions are rained as essence bobby which is unrecoverable. The situation is dangerous for it can affect in short- circuit between anode and cathode. For the cathode, the cobalt oxide or manganese oxide will be perished after numerous cycles under low voltage. Meanwhile, oxygen will be released and the battery suffers from capacity loss. The battery temperature should be controlled precisely. Both redundant heat and lack of heat will bring about problems. Chemical response rates have a direct relation to temperature. The drop of the operating temperature will reduce response rate and the capacity of carrying current during charging or discharging. In other words, the battery power capacity is dropped. Also, the reduction of response rate makes it harder to fit lithium ions into intercalation spaces. The result is the reduction of power and lithium plating causing the capacity loss. High temperature increases the response rate with advanced power affair; still, it also increases the heat dispersion and generates indeed advanced temperatures. Unless heat is dissipated quicker than heat is generated, the temperature will be advanced and eventually a thermal raw will affect. Thermal raw consists of several stages and each stage will give rise to further unrecoverable damage to cells. First, the SEI subcase is dissolved to electrolyte at round 80ºC. The primary overheating may affect from inordinate current or high ambient temperature. After breakdown of the SEI subcase, electrolyte begins to reply with the anode. This response is exo- thermal which drives the temperature advanced. Secondly, the advanced temperature causes the organic detergents to break down with the release of hydrocarbon feasts. Typically this starts at around 110 ºC. The pressure inside cells is erected up by the gas and the temperature is beyond the flashpoint. Still, the gas doesn't burn due to the lack of oxygen. A articulation is demanded to release the gas in order to keep cells under proper pressure and avoid a possible rupture. Also, the division is melted and short- circuits do between the anode and cathode at 135 ºC. Eventually, the essence- oxide cathode breaks down at 200 ºC and releases oxygen which allows the electrolyte and hydrogen gas to burn. This response is also exo- thermal and drives temperature and pressure still further. In addition, uneven temperature distribution is another problem of batteries. Generally, it's caused by the inordinate original temperature, variable current in a cell and the thermal conductivity of the case, as well as the placement of positive and negative outstations and so on. It results in original deterioration and indeed thermal raw with reducing the battery continuance.

Operating Requirements

The battery temperature should be controlled within temperature limits to avoid the thermal issues and improve the performance. The temperature range affects the battery power and battery cycle life. At the same time, the temperature distribution should be even to guarantee the battery performance and lifetime. That is also the reason why the battery thermal management system is necessary to the battery system.

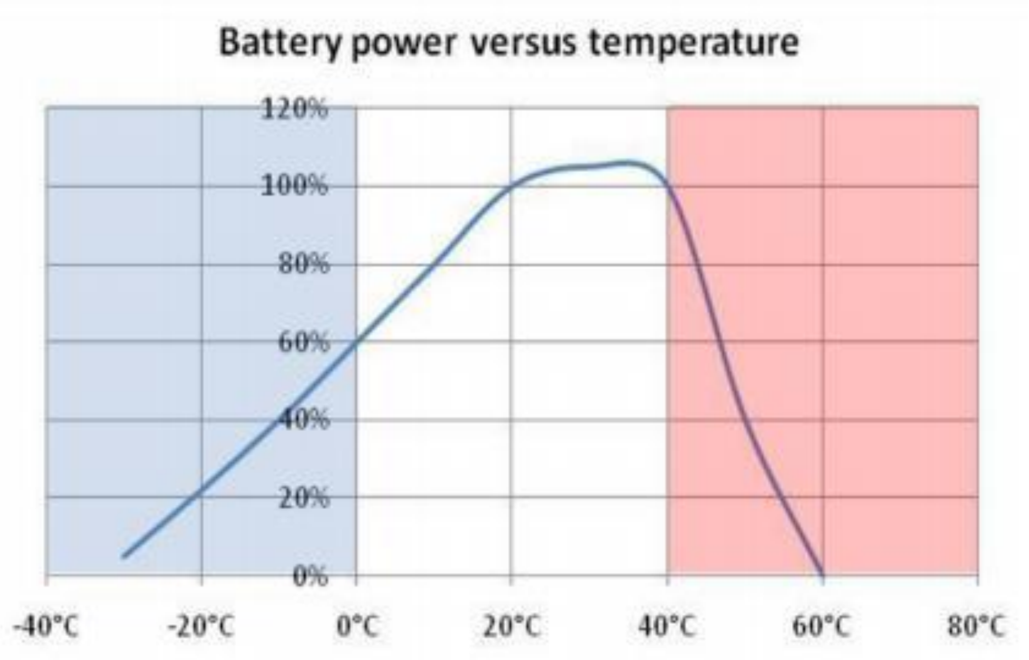


Fig 1.2 Battery power and temperature

When temperature ranges from 20°C to 40°C, battery power reaches maximum,

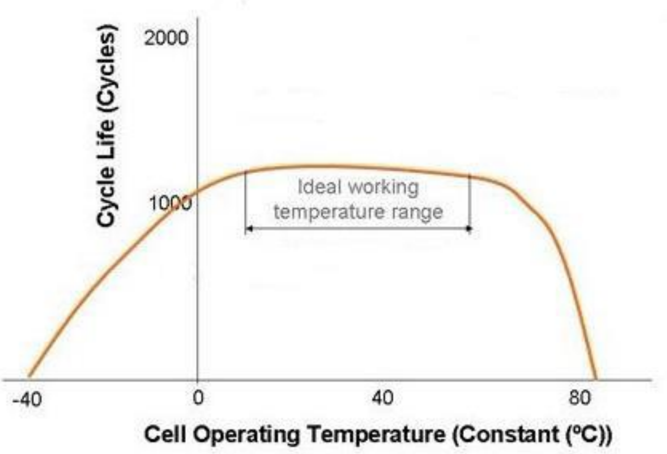


Fig 1.3 Cycle life and temperature

The cycle life goes down slowly below 10°C because of anode plating and drops off quickly above 60°C due to the breakdown of electrode materials. Generally, the temperature must be controlled between 20°C and 40°C to ensure the performance and cycle life. Moreover, the temperature distribution is controlled under 5K to keep the safety and lifetime of battery. In addition, ventilation is also essential to the battery system and should be taken into account.

1.2 Heat Transfer

Overall Heat Transfer Co-efficient

To predict the performance of the heat exchange, the heat transfer can generally be expressed using overall heat transfer co-efficient by following equation

$q = UA\Delta TM$

Where

q Heat transfer rate [W]

U Overall heat transfer coefficient [W/ (m²·K)]

A Heat transfer surface area [m²]

ΔTM Approximate mean temperature different [K]

For the un-finned, tubular heat exchanger of Figure 2.4, the overall heat transfer coefficient can by expressed

$$\frac{1}{UA} = \frac{1}{h_i A_i} + \frac{R''_{f,i}}{A_i} + R_w + \frac{R''_{f,o}}{A_o} + \frac{1}{h_o A_o}$$

Where

UA Product of U and A [W/K], A could be either Ai or Ao.

hi,ho Convective heat transfer co-efficient of inner, outer tube surface [W/m²]

Ai,o Contact area of inner, outer tube surface [m²]

Rf,$''$,Rf,o'' Fouling Factors [m²·K/W]

Rw Conductive resistance [K/W]

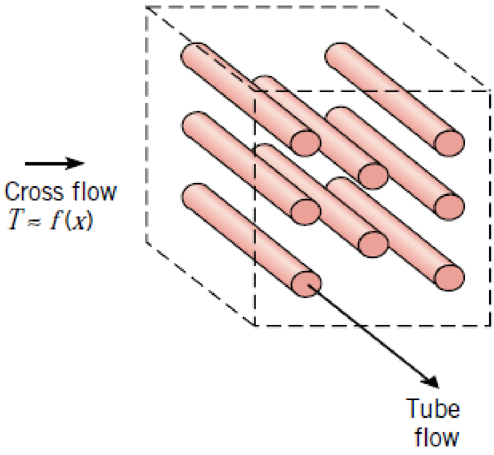


Fig 1.4 Un-finned, tubular cross-flow heat exchanger

BTMS

A Battery Thermal Management System (BTMS) is a technology designed to regulate and control the temperature of batteries in various applications, such as electric vehicles (EVs), hybrid electric vehicles (HEVs), and renewable energy storage systems.

1.3 Battery Thermal Conditioning

The battery thermal management system is one of the main aspects of an EV. Therefore, a major focus area for research is the optimal working temperature range of batteries during charging/discharging mode and the associated thermal management. Since thermal runaway leads to fire in battery packs, regulating the battery temperature within a safe range of 25 ◦C to 40 ◦C during charging and discharging cycles in EVs is essential for the battery's longevity and safety and the ideal temperature distribution between batteries in the battery pack should be below 5 ◦C. When the battery temperature is higher than 50 ◦C, the charging speed, efficiency, and lifespan are reduced

1.4 Types of Battery Thermal Management system

1.4.1 Liquid Cooling

Overview

- Coolant Circulation: In a liquid cooling system, a coolant (usually a mixture of water and a heat transfer fluid) circulates through a network of pipes or channels within the battery pack.
- Heat Exchange: The coolant absorbs heat from the battery cells and carries it away to a heat exchanger.

Components

- Heat Exchanger: This component transfers heat from the coolant to the external environment. It can be air-cooled or liquid-cooled, depending on the design.
- Pumps: Circulate the coolant through the battery pack and the heat exchanger.
- Thermal Sensors: Monitor the temperature of the battery cells to provide feedback for the cooling system.

Advantages

- Temperature Control: Liquid cooling allows for precise control of the temperature within the battery pack, optimizing performance and safety.
- Uniform Cooling: Ensures even cooling across all cells, preventing hotspots.
- Efficiency: Liquid cooling is often more efficient than air cooling, especially in high-temperature environments.

Safety and Performance

- Preventing Thermal Runaway: Effective cooling helps prevent the overheating of batteries, reducing the risk of thermal runaway.
- Extended Lifespan: Maintaining optimal temperature conditions can contribute to the longevity of the battery pack.

Challenges

- Complexity: Liquid cooling systems can be more complex to design and maintain compared to air cooling.
- Weight and Cost: Adding a liquid cooling system may increase the overall weight and cost of the battery pack and the vehicle.

Applications

- Electric Vehicles: Liquid cooling is commonly used in electric cars to manage the temperature of the traction battery.
- Stationary Energy Storage: Large-scale battery systems for grid storage also utilize liquid cooling.

1.4.2 Air Cooling

Air Flow Design

- **Air Circulation:** The battery pack is designed with channels or fins that facilitate the natural or forced circulation of air.
- **Fans or Blowers:** Fans or blowers are often incorporated to enhance airflow and cooling efficiency.

Heat Dissipation

- **Convective Cooling:** Heat is transferred from the battery cells to the surrounding air through convection.
- **Radiative Cooling:** In some cases, radiation can contribute to heat dissipation.

Components

- **Cooling Fins:** Fins or other heat exchange surfaces increase the surface area for better heat dissipation.
- **Fans/Blowers:** Used to enhance the natural convective cooling by increasing airflow.

Advantages

- **Simplicity:** Air cooling systems are generally simpler in design and may be lighter compared to liquid cooling systems.
- **Cost-Effective:** Air cooling systems can be more cost-effective to implement and maintain.
- **Lower Weight:** Generally, air-cooled systems may have lower weight compared to liquid-cooled systems.

Challenges

- **Temperature Control:** Air cooling might be less precise in maintaining consistent temperatures compared to liquid cooling.
- **Hotspots:** In certain conditions, air cooling might lead to uneven cooling and potential hotspots.
- **Limited Cooling in High Temperatures:** In extremely high-temperature environments, air cooling might be less effective.

Applications

- **Electric Vehicles:** Many electric vehicles use air cooling for battery thermal management, especially in smaller and lighter vehicles.
- **Consumer Electronics:** Air cooling is common in smaller-scale batteries used in laptops, smartphones, and other portable devices.

1.4.3 Phase Change Material (PCM)

Principle of Operation

- Melting and Solidification: PCMs absorb and release large amounts of latent heat during the phase transition (melting or solidification) at a specific temperature.
- Temperature Regulation: PCMs can be integrated into the battery pack to regulate temperature by absorbing excess heat during charging or discharging and releasing heat during periods of lower activity.

Components

- PCM Modules: PCMs are typically encapsulated in containers or modules within the battery pack.
- Distribution System: Channels or structures facilitate the flow of heat between the battery cells and the PCM.

Advantages

- Thermal Regulation: PCMs provide effective temperature regulation by absorbing and releasing heat during phase transitions.
- Reduced Hotspots: The use of PCMs can help mitigate temperature variations and reduce the risk of hotspots in the battery pack.

- Extended Lifespan: Maintaining a more consistent temperature can contribute to the longevity of the battery cells.

Challenges

- Limited Operating Range: PCMs have a specific temperature range at which they undergo phase transitions, and selecting the appropriate PCM is crucial for the intended application.
- Integration Complexity: Designing an effective system for PCM integration into the battery pack can be complex.

Applications

- Electric Vehicles: PCMs are increasingly used in electric vehicle battery packs to enhance thermal management and extend battery life.
- Grid Storage: Large-scale energy storage systems also benefit from PCM technology to improve thermal performance.

Liquid cooling BTMS improvement

The optimization methods for liquid cooling BTMS can be divided into three categories: coolant, system structure, and improvement of liquid cooling-based hybrid systems. The system structure includes the cooling fluid channel, cooling plate, and heat transfer casing.

Coolant improvement

The liquid cooling system has good conductivity, allowing the battery to operate in a suitable environment, which is important for ensuring the normal operation of the lithium-ion battery. Commonly used coolants in cooling systems include oil, water, Nanofluids, liquid metals, and boiling liquids.

The four advanced coolants reviewed in this section are oil, electrically conductive coolants, liquid metal or nanoparticle-added coolants, and special coolants.

1.5 Coolants

Dielectric coolant

Dielectric coolants are stable, non-flammable, and environmentally friendly even at high temperatures. Based on research results, liquid cooling based on dielectric coolants is an effective cooling technology that can effectively cool the battery pack under high continuous discharge cycle conditions. The lithium-ion battery thermal management system proposed by Al-Zareer employs boiling liquid propane to remove the heat generated by the battery, while propane vapor is used to cool parts of the battery not covered by liquid propane. The impact of the height of the liquid propane inside the battery pack on the thermal behaviour of the battery pack was analysed. The results show that the propane-based thermal management system provides good cooling control of the battery temperature under high continuous discharge cycle conditions of 7.5C. However, safety must be considered when using liquid propane as a coolant as it is a flammable gas. In addition, the physical properties of liquid propane must also be considered in the design of the cooling system to ensure it can effectively cool the battery pack. An et al proposed a new thermal management system based on the hydrophobic electrolyte hydrogen fluoride liquid at a boiling point of 34 1C. Cooling experiments of the battery module were performed under different discharge rates and flow recovery numbers. NOVEC 7000 has a boiling temperature of 34 1C under one atmosphere, which falls within the optimal operating temperature range of 25–40 1C for lithium-ion batteries. The results showed that the highest temperature of the battery pack (10 1 h battery strings in series) could be maintained at 35 1C even with a discharge rate as high as 20C.

Liquid metal and nanoparticle

Liquid metals are metals or metal alloys that are in the liquid state at or near room temperature. The most common liquid metal is mercury, but recent advancements have focused on gallium and its alloys, particularly the eutectic alloy of gallium, indium, and tin (EGaIn), which remains liquid at room temperature and is less toxic than mercury.

Properties and Advantages:

1. **High Thermal Conductivity:** Liquid metals exhibit excellent thermal conductivity, making them ideal for heat transfer applications.
2. **High Electrical Conductivity:** They are also good electrical conductors, useful in flexible electronics and reconfigurable circuits.
3. **Flexibility and Fluidity:** Their liquid state allows for easy molding and shaping, which is beneficial in various applications including soft robotics and self-healing materials.

Applications:

1. **Flexible Electronics:** Liquid metals can be used to create stretchable circuits that maintain conductivity even when deformed.
2. **Thermal Management:** Their high thermal conductivity makes them ideal for use in cooling systems for electronics and power devices.
3. **Biomedical Devices:** Non-toxic liquid metals like gallium alloys are being explored for use in medical implants and devices due to their biocompatibility and ability to form conformal interfaces.

Nanoparticles

Nanoparticles are particles with at least one dimension less than 100 nanometers. They exhibit unique physical and chemical properties due to their small size and large surface area relative to their volume.

Properties and Advantages

1. **Enhanced Reactivity** The large surface area of nanoparticles makes them highly reactive, which is beneficial in catalysis and chemical reactions.
2. **Optical Properties** Nanoparticles exhibit unique optical properties such as quantum confinement and surface plasmon resonance, which are useful in imaging and sensing applications.
3. **Mechanical Strength** Incorporating nanoparticles into materials can enhance their mechanical properties, such as strength and durability.

Applications

1. **Medicine** Nanoparticles are used in drug delivery systems to target specific cells or tissues, improving the efficacy and reducing side effects of treatments. They are also used in imaging for diagnostic purposes.
2. **Electronics** In electronics, nanoparticles are used to develop components like transistors and sensors with enhanced performance due to their size-dependent properties.
3. **Environmental Remediation** Nanoparticles can be used to remove contaminants from water and air through adsorption and catalytic degradation.

Synergy of Liquid Metal and Nanoparticles

Combining liquid metals and nanoparticles opens up a new realm of possibilities. This hybrid approach leverages the advantageous properties of both materials to create advanced composites with superior performance.

Nanoparticle-Enhanced Liquid Metals

1. **Improved Thermal and Electrical Conductivity** Dispersing nanoparticles within liquid metals can further enhance their thermal and electrical properties, making them even more effective for cooling and electrical applications.
2. **Tailored Mechanical Properties** The mechanical properties of liquid metals can be tuned by incorporating nanoparticles, which can improve the strength and durability of the resulting composite materials.
3. **Novel Functionalities** The synergy between liquid metals and nanoparticles can lead to new functionalities, such as self-healing materials where the fluidity of the liquid metal allows it to flow and fill cracks, while the nanoparticles enhance the overall strength.

Applications

1. **Advanced Electronics** These composites can be used to develop next-generation electronic devices that are flexible, durable, and highly conductive.
2. **Smart Materials** In the field of smart materials, the combination can lead to the development of materials that respond dynamically to environmental changes, such as temperature or pressure, making them useful in sensors and actuators.
3. **Biomedical Engineering** The biocompatibility and enhanced properties of these materials make them suitable for innovative biomedical applications, such as wearable health monitors and implantable devices.

Conclusion

The integration of liquid metals and nanoparticles represents a significant advancement in material science, offering new solutions for various technological challenges. Their unique properties and the ability to tailor these properties for specific applications make them promising candidates for future innovations in electronics, medicine, and beyond.

Unconventional coolant materials and coolants

Novel unconventional coolants and coolant control strategies have also been studied for specific lithium-ion battery thermal management. A new type of subcritical CO2, which is used to control the temperature of lithium-ion batteries. The feasibility and superiority of subcritical CO2 as a thermal management medium were investigated through numerical simulation. It was found that the supercritical CO2 near the critical point has the advantages of phase change material and liquid medium combined, becoming an important medium in the battery thermal management system. a battery thermal management system (BTMS) with reciprocating liquid flow. The effect of reciprocating cycles, cooling fluid flow rate of the battery module, and environmental temperature on battery temperature and temperature imbalance were studied. Compared to unidirectional flow, the average temperature difference and heat consumption of the reciprocating liquid flow heating system can be reduced by 1.2C and 14 kJ, with a cycle of 295 seconds.

Therefore, by adopting the reciprocating liquid flow BTMS, the thermal characteristics and temperature uniformity can be effectively improved, and the parasitic power consumption can be significantly reduced

1.6 Liquid-Cooled BTMS

Liquid cooling can be divided into indirect cooling and direct cooling (also known as immersion cooling), depending on whether the coolant is in contact with the battery, as shown in Figure 1.1.4. Indirect liquid cooling usually involves placing cooling plates, discrete tubes, or jackets on the surface of the cell. This cooling technique moves the heat produced by the battery to the outside with the flowing coolant, avoiding direct contact between the coolant and the battery. In direct liquid cooling, the coolant is in direct contact with the battery, which requires the use of non-conductive medium fluid as coolant. Direct liquid cooling greatly improves the contact area between the battery and the coolant, thereby obtaining an extremely high heat transfer rate. Direct liquid cooling can be divided into single phase and two phase, according to whether the coolant has phase change. Compared with indirect liquid cooling, direct liquid cooling shows a better cooling effect and can improve the uniformity of temperature distribution. As the battery and coolant are in direct contact, this reduces the need for complex flow path designs and reduces the risk of accidental leakage of coolant, which could cause short circuits in the battery. Although direct liquid cooling is considered to be a better choice for the BTMS in the future, it has not been commonly used in electric vehicle. In this section, the main research progress of indirect liquid cooling and direct liquid cooling is introduced. Secondly, the research of different coolants in each part is summarized and analysed. Finally, attention is paid to the composite cooling system based on liquid cooling.

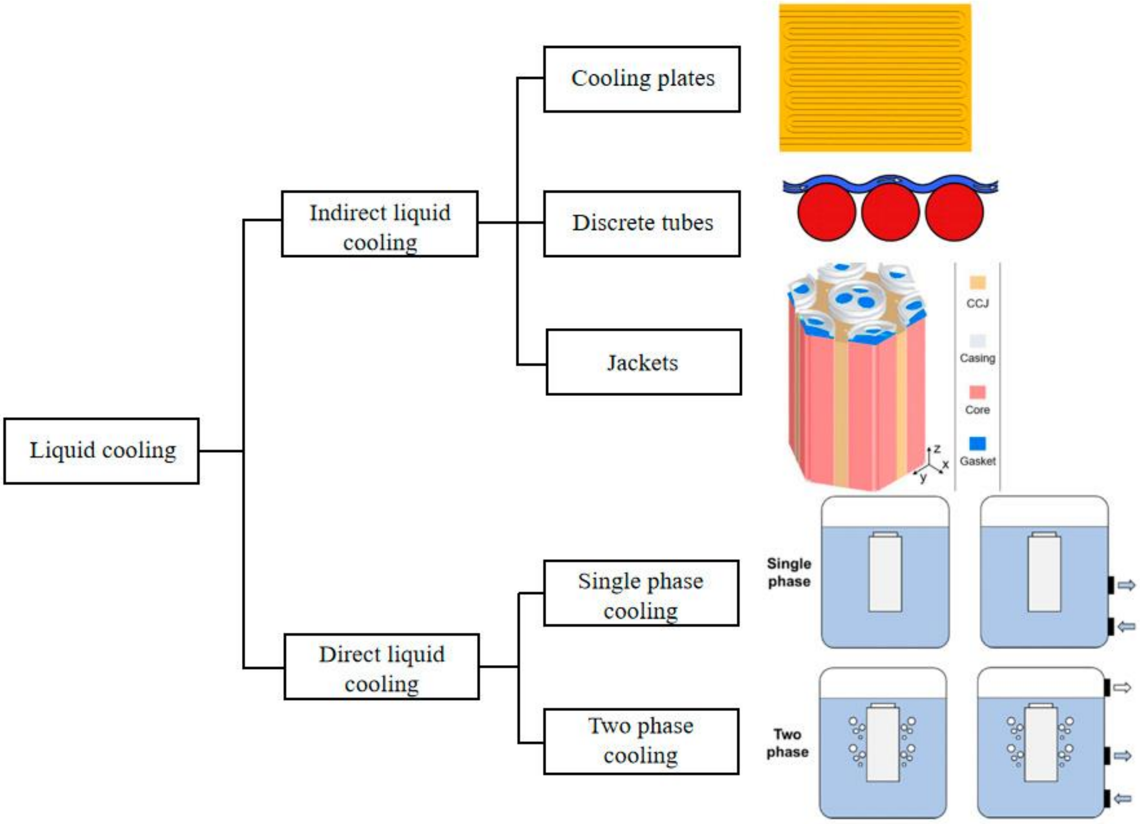


Fig 1.5 recent progress in liquid thermal management

Indirect Liquid Cooling

In indirect liquid cooling, different shapes of batteries are suitable for different cooling devices. Cylindrical batteries usually use discrete tubes or jackets in order to have a larger contact area between the surface and the coolant. For prismatic batteries or pouch batteries, flat cold plates are usually the best choice. The air gap between the cooling plate or tube and the battery will contribute to heat insulation and lower heat transfer efficiency as a result of the coolant and battery not making direct contact with each other. A high-precision cold metal plate, as well as a high-thermal-conductivity grease or epoxy bonding agent, are required to eliminate air gaps, thereby reducing thermal contact resistance. In order to improve the heat dissipation of the battery, researchers have conducted many studies on indirect liquid cooling. The selection of coolants, the design of flow channels, and the optimization of system structures have received a lot of attention, and these studies are covered in this section.

Flow Channel Optimization Design

In indirect liquid cooling, the coolant needs to pass through specific channels. However, different channel designs can have different effects on the thermal performance and energy consumption of the BTMS, so researchers have carried out many studies on channels. For the geometry of the cold plate channels, typical designs are shown in Figure 5. A multichannel parallel cold plate. The effects of channel number, flow direction, mass flow rate, and ambient temperature on battery temperature were studied by numerical simulation. The CFD method numerically simulated the serpentine channel cold plate to determine the optimal design of the objective function of cooling hydraulic drop, temperature uniformity, and average temperature; and studied the influence of boundary condition changes on the performance of the cold plate. The cold plate channel, its shape is mostly linear along the flow direction, and the resistance will increase when the coolant flows in the pipeline.

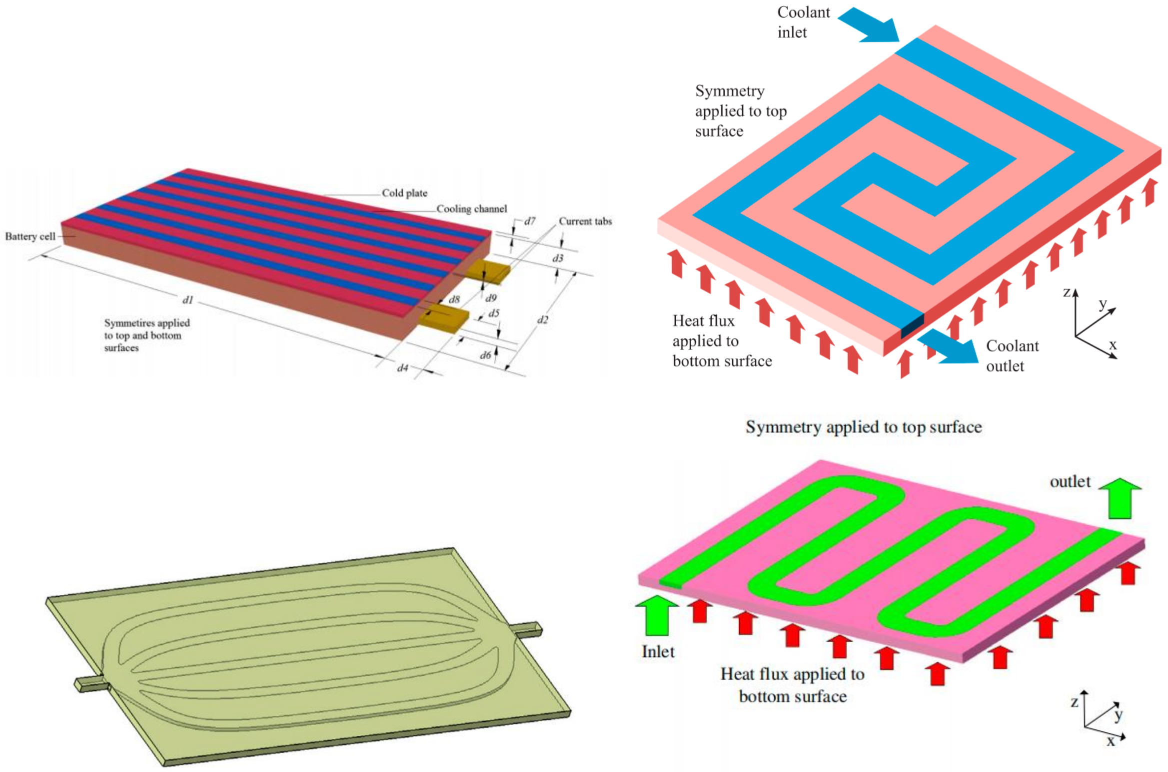


Fig 1.6 typical design of the channel: (a) parallel channel (b) serpentine channel(c) Streamlined channel (d) U-shaped serpentine channel

Based on the typical channel structure, parallel channels, and serpentine channels are gradually replaced by channels with a better cooling effect. Comparing six cold plate designs with the same channel volume, as shown in Figure 6a, which are straight channel, serpentine channel, U-shaped channel, pumpkin-shaped channel, spiral channel, and hexagonal structure channel. Through numerical analysis, it was discovered that, despite having a high-pressure drop, the snake channel and hexagonal channel have good cooling properties and can significantly improve the temperature distribution of the battery pack. In contrast, the pumpkin-shaped channel is useful for lowering the pressure drop and pumping power. In another study, comparing the performance of the cold plate of the snake channel with that of the parallel channel, it was also found that the pressure drop of the snake channel was greater than that of the parallel channel. Moreover, Chen et al. studied the cooling performance of the BTMS based on a parallel Mini channel cold plate (PMCP), and designed three different flow channels of PMCP.

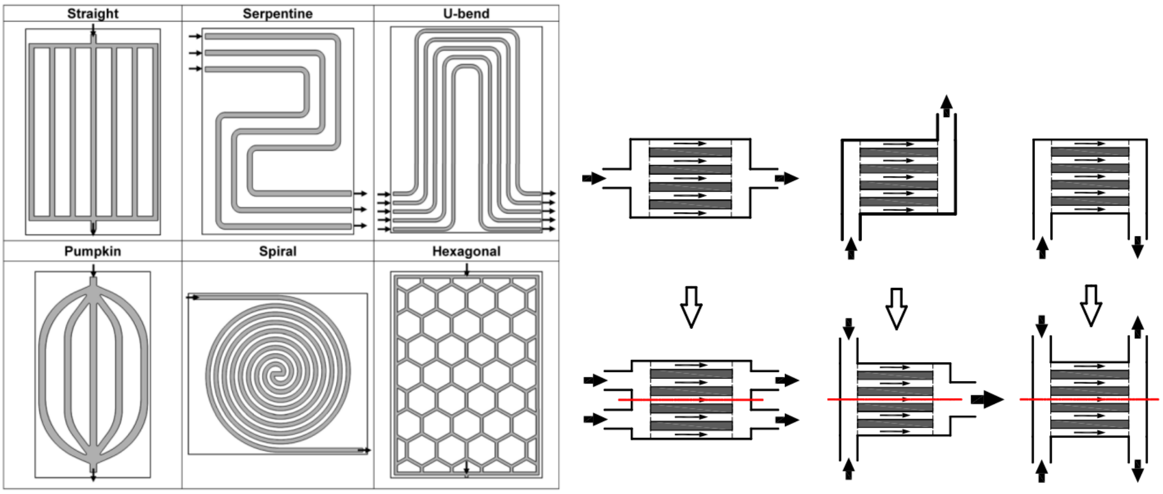


Fig:1.7 Flow pattern and flow direction

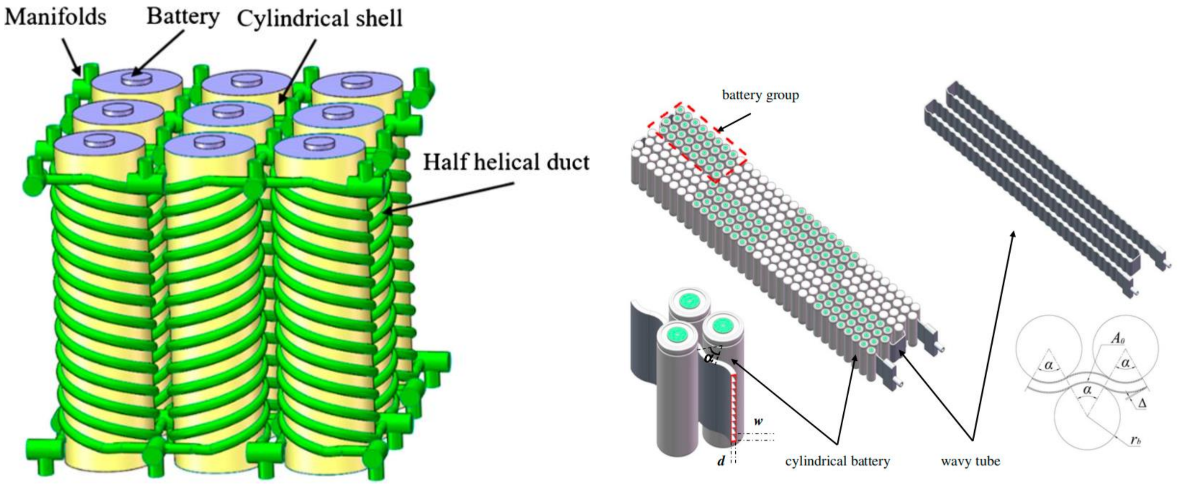


Fig 1.8 Liquid cooling technology

2. LITERATURE SURVEY

Sl No	Paper Title	Year	Author	Inference
1	Battery Thermal Management Systems of Electric Vehicles	2014	Jiling Li Zhen Zhu	In this paper, they have gone through different types of technologies to cool and heat the battery system. They have done CLS and PCM model and they have compared the results of both models.
2	Design Of Battery Thermal Management System Of Electric Vehicle for Indian Scenario	2022	Chinmay Dabholkar, Jay Naik, Harsh Harale	In this review, they have calculated the heat dissipated with respect to range and other parameters. They have used liquid cooling system to meet the requirements and used ANSYS to analyse to increase the accuracy.
3	Study on the Heat Dissipation Performance of a Liquid Cooling Battery Pack with Different Pin-Fins	2023	Maokun Xiong, Ningbo Wang, Wei Li	In this paper, they have used liquid cooling system to dissipate the heat. They have attached different shape, number and distribution fins and analysed which factor affects the most in heat dissipation.
4	Review of the Li-Ion Battery, Thermal Management, and AI-Based Battery Management System for EV Application	2022	Maryam Ghalkhani, Saeid Habibi	In this review, they have studied different types of cooling methods to increase the performance. They have noticed that the air-cooled system has more advantageous features.
5	Thermal management system for lithium-ion batteries	2022	Kevin Wang Jonathan Ripheden	In this paper they have studied different types of cooling systems. They focused on the liquid cooling method where they studied shapes, placements and route of the pipe and gave conclusion about the performance.
6	Optimizing the Heat Dissipation of an Electric Vehicle Battery Pack	2014	Hsiu-Ying Hwang, Yi-Shin Chen, and Jia-Shiun Chen	The study proposes a new kind of air-cooling ventilation system for battery pack of an electric vehicle different from the traditional series ventilation system, by changing the locations of cooling air inlets and outlets, shapes of outlet, and combining with uneven size of gap among cells.

7	A Review of Cooling Technologies in Lithium-Ion Power Battery Thermal Management Systems for New Energy Vehicles	2023	Ping Fu, Lan Zhao	In this paper they have studied various methods of cooling and they have come upon the method of hybrid cooling system.

3. PROBLEM DEFINITION

One common problem in Battery Thermal Management Systems (BTMS) is the challenge of maintaining optimal temperature uniformity across all cells within a battery pack. This issue is crucial because temperature variations can lead to uneven stress on individual cells, potentially causing hotspots, reduced efficiency, and accelerated degradation.

Other problems are mentioned below

Temperature Extremes

- **Overheating** During high-power operations or fast-charging, batteries can experience elevated temperatures, risking thermal runaway, accelerated degradation, and safety hazards.
- **Cold Weather Impact** Low temperatures can reduce battery efficiency, limit power output, and increase internal resistance, adversely affecting overall performance.

Safety Concerns

- **Risk of Thermal Runaway** Uncontrolled temperature increases can lead to thermal runaway, posing a serious safety risk, especially in applications like electric vehicles where large battery packs are in use.
- **Fire Hazards** Excessive heat can contribute to fire hazards, necessitating effective measures to prevent and mitigate such incidents.

Performance Degradation

- **Cycle Life Reduction** Elevated temperatures accelerate chemical reactions within the battery, leading to premature degradation and a reduced number of charge-discharge cycles.
- **Power Output Limitations** Inconsistent temperature control can result in variations in power output, affecting the overall efficiency and performance of the battery.

Charging Challenges

- **Fast Charging Limitations** The demand for fast-charging capabilities is hindered by the heat generated during the process. Efficient thermal management is essential to enable safe and rapid charging without compromising battery health.

Efficiency Loss

- **Energy Wastage** Inadequate thermal management can result in energy wastage in the form of heat, reducing the overall efficiency of the battery system and affecting its environmental sustainability.

User Experience Impact

- **Inconsistent Performance** Temperature-related fluctuations in battery performance can lead to an inconsistent user experience, affecting the reliability and predictability of the battery-powered systems.

4. OBJECTIVES

Safety Assurance

- Objective: Prevent thermal runaway and minimize the risk of fire hazards.

- Rationale: Ensuring the safety of the battery system and surrounding components is paramount, especially in applications with large battery packs, such as electric vehicles.

Cycle Life Extension

- Objective: Minimize temperature-induced degradation to extend the overall lifespan of the battery.
- Rationale: Prolonging the cycle life of the battery contributes to its economic viability and reduces the frequency of replacements.

Efficient Fast Charging

- Objective: Enable fast-charging capabilities without compromising battery health.
- Rationale: Meeting the demand for rapid charging in various applications, such as electric vehicles, while maintaining safety and long-term reliability.

Consistent Performance

- Objective: Stabilize power output and energy efficiency across a range of operating conditions.
- Rationale: Providing a consistent and predictable user experience, especially in applications where battery performance is critical.

Optimized Energy Efficiency

- Objective: Minimize energy wastage due to excess heat, improving overall system efficiency.
- Rationale: Enhancing the energy efficiency of the battery system contributes to sustainability and reduced environmental impact.

Adaptability to Environmental Conditions

- Objective: Ensure effective thermal management under various environmental conditions, including extreme temperatures.
- Rationale: Battery systems should be capable of operating reliably in diverse climates and usage scenarios.

5. METHODOLOGY

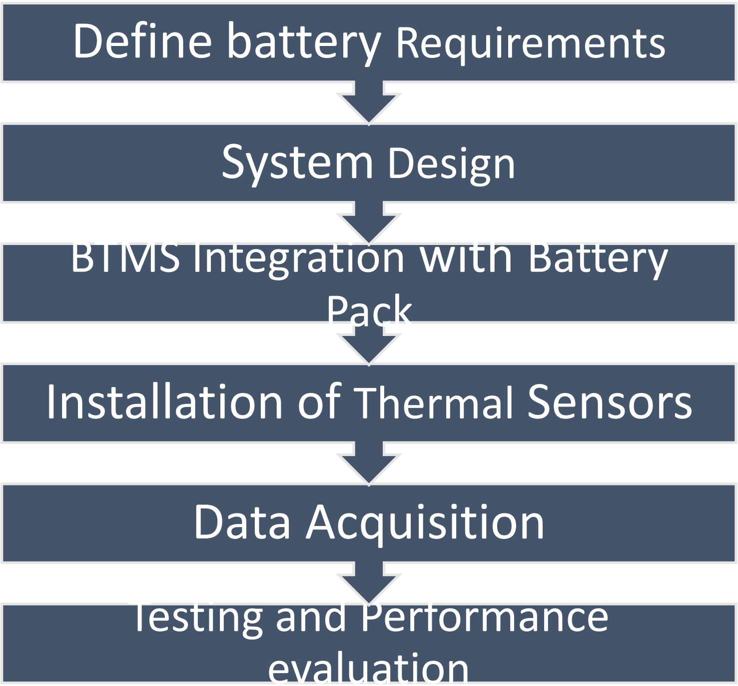


Fig 3.1.1 Methodology flowchart

1. **System Design**

- **Define Requirements:** Establish the specific thermal requirements for the battery system based on the application, type of batteries used, and environmental conditions.
- **Integration with Battery Pack:** Integrate thermal management components seamlessly into the overall battery pack design, considering factors such as size, weight, and compatibility with other system components.

2. **Sensors and Monitoring**

- **Install Thermal Sensors:** Distribute temperature sensors strategically within the battery pack to monitor the temperature of individual cells and key components.

3. **Data Acquisition**

- **Real-Time Data Collection:** Implement a data acquisition system to collect real-time temperature data from the sensors.
- **Data Logging:** Log temperature data over time to identify trends, patterns, and potential issues.

4. **Integration with Battery Management System (BMS)**

- **BMS Integration:** Ensure seamless integration with the Battery Management System to coordinate thermal management with other aspects of battery operation, such as state of charge, state of health, and voltage control.

5. **Testing and Validation**

- **Testing:** Conduct thorough testing to validate the effectiveness of the thermal management system under various operating conditions.

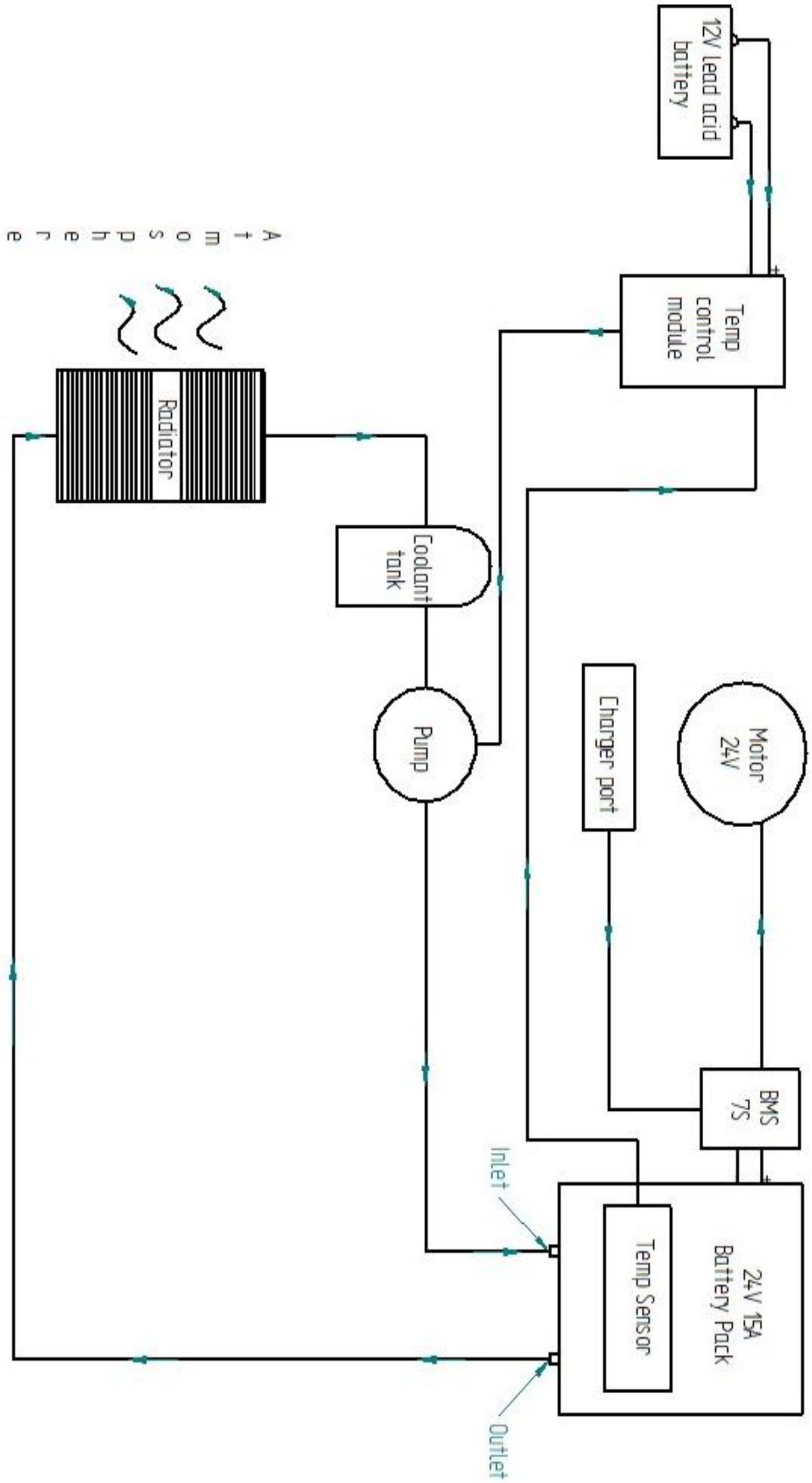
6. **Continuous Monitoring and Maintenance**

- **Continuous Monitoring:** Implement continuous monitoring of the BTMS performance in real-world conditions to identify and address any deviations from expected behaviour.

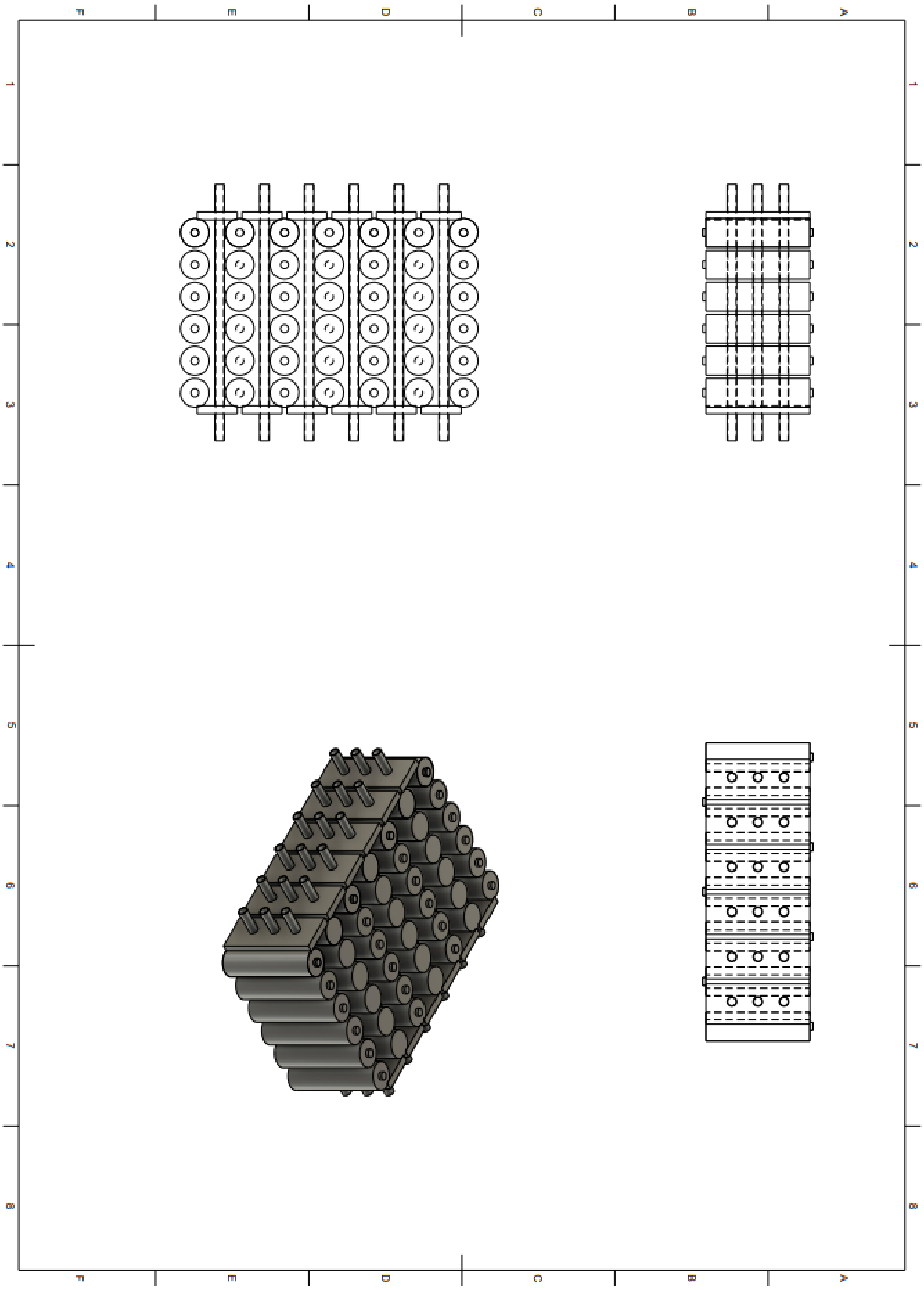
7. **Maintenance Protocols** Develop maintenance protocols to ensure the ongoing reliability and performance of the thermal management system over the battery pack's lifespan.

6. DESIGN ASPECTS AND FABRICATION PROCESS

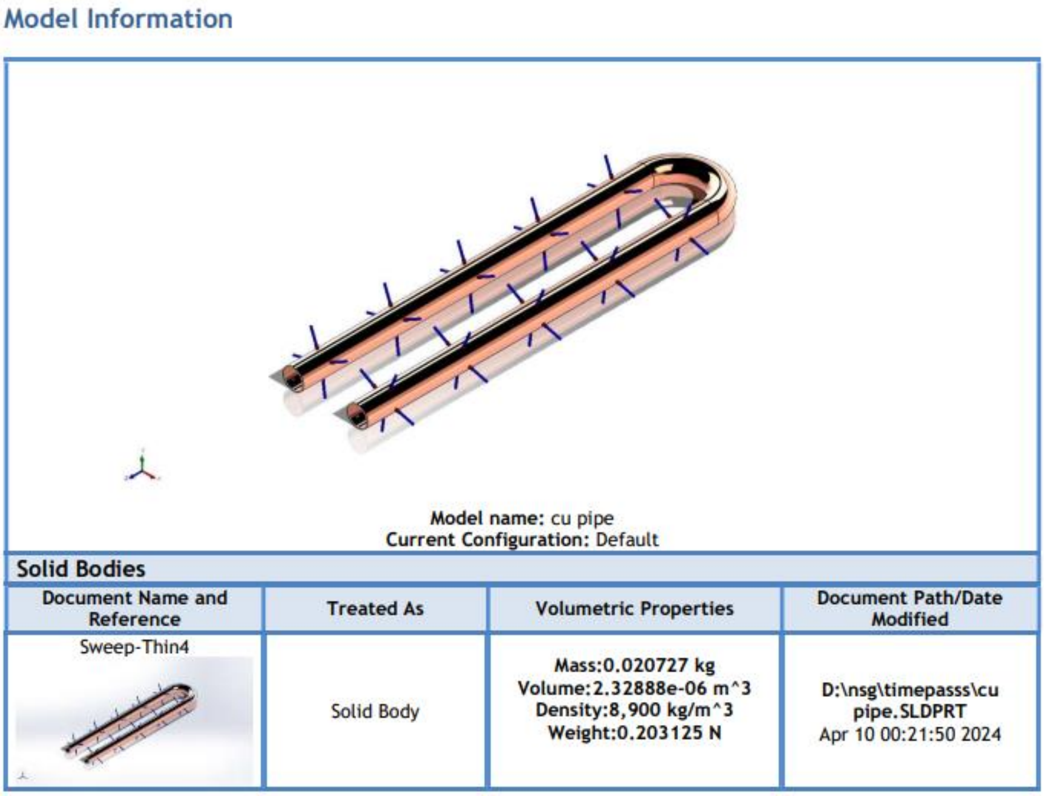
6.1 CIRCUIT DIAGRAM



6.2 CAD MODEL



6.3 SIMULATION

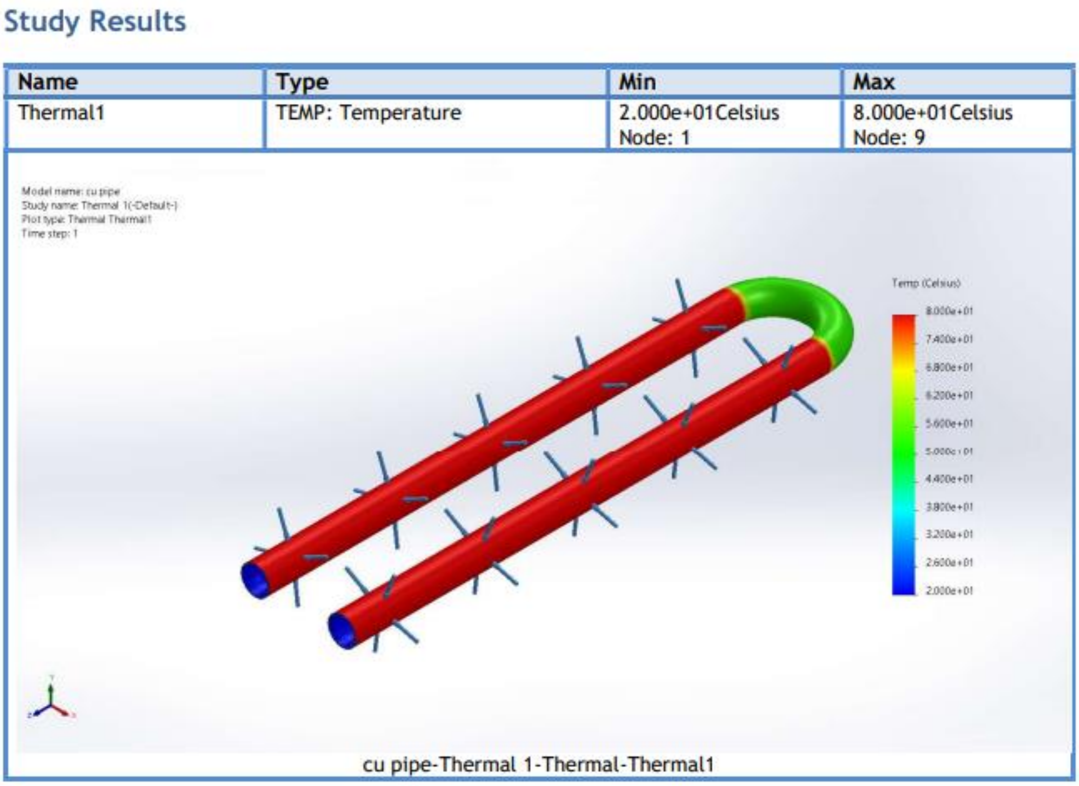


Model Information

Model name: cu pipe
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Sweep-Thin4	Solid Body	Mass:0.020727 kg Volume:2.32888e-06 m^3 Density:8,900 kg/m^3 Weight:0.203125 N	D:\nsg\timepasss\cu pipe.SLDPRT Apr 10 00:21:50 2024

Fig 3.1.1 Model information



Study Results

Name	Type	Min	Max
Thermal1	TEMP: Temperature	2.000e+01Celsius Node: 1	8.000e+01Celsius Node: 9

Model name: cu pipe
Study name: Thermal 1(-Default-)
Plot type: Thermal Thermal1
Time step: 1

cu pipe-Thermal 1-Thermal-Thermal1

Fig 3.1.1 Study results

6.4 MODEL PHOTOS

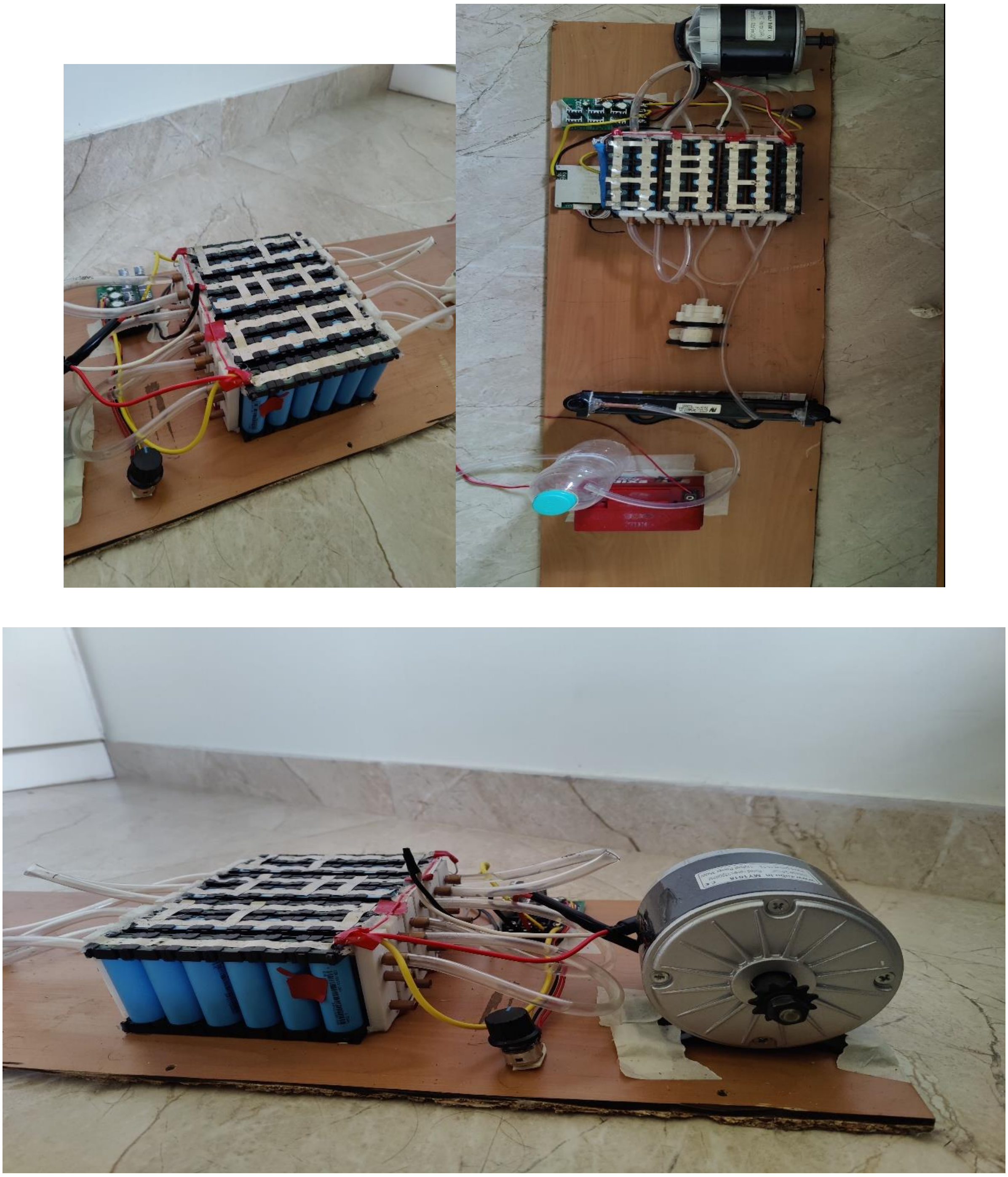


Fig 8.1.2 Model pitctures

6.5 Fabrication Process

1. Design Phase:

- **Battery Pack Configuration**: Determined the configuration i.e. 7S6P for a 24V pack with 15Ah capacity (with six cells in parallel and seven cells in series). This affects the voltage and capacity of the pack.

- **3D Model Design**: Used CAD software (Solidworks) to design the battery pack casing and cell holders. Ensure the design includes compartments for cells, space for the Copper pipes and channels for wiring.

2. 3D Printing:

- **Printed the Case and Holders**: Loaded the design into the 3D printer and print the battery pack casing and cell holders. Make sure the dimensions are accurate to securely hold the 18650 cells.

Fig 5.1 3D printing process

Post-Processing: Removed any supports and smoothened out rough edges from the printed parts. Drilled the holes into the cell spacers to accommodate the copper pipes

Fig 5.2 Post-processing

3. Cell Preparation

- **Check Cells**: Measured the voltage of each 18650 cell to ensure they are within a safe range and have similar voltage levels.
- **Group Cells**: Arranged the cells according to the planned configuration.

4. Assembly

- **Insert Cells**: Placed the 18650 cells into the Cell holders. Ensure they are firmly seated.
- **Nickel Strip Welding**: Use a spot welder to connect the cells with nickel strips. For a 7S6P configuration:
- Connect the positive terminal of one cell to the negative terminal of the next cell in series.
- Repeat for all cells in the series.
- Connect parallel cells by welding additional nickel strips across the cells' terminals.

5. Wiring

- **BMS Integration**: Attach the BMS to the battery pack. Connect the BMS's wires to the corresponding terminals on the battery pack:
- **B-** to the battery pack's main negative terminal.
- **B+** to the battery pack's main positive terminal.
- **Balance Leads**: Connect the balance leads to the appropriate points between cells in series.
- **Insulation**: Use heat shrink tubing to cover exposed connections and ensure they are insulated to prevent shorts.

6. Securing Components

- **Hot Glue**: Apply hot glue to secure the BMS and any loose wires within the casing.

7.1 Calculation of Coolant Pipe Diameter

To find the coolant pipe diameter needed to extract heat from a system, we'll need to use several thermodynamic principles and equations. Here's a step-by-step method to calculate the required pipe diameter:

1. **Determine the amount of heat to be removed (Q):**

- Assuming extracting 80 degrees of heat, we need the actual heat energy to be removed, which is typically in units of watts (W) or joules per second (J/s). Assuming cooling from 80°C to 40°C, we need the heat capacity and flow rate of the coolant to find this.

2. **Calculate the heat transfer rate (Q):**

- Using the formula $Q=m^{\cdot}\cdot cp\cdot\Delta T$
- m= mass flow rate of the coolant (kg/s)
- cp= specific heat capacity of the coolant (J/kg·K)
- ΔT= temperature difference (K)

3. **Determine the coolant flow rate:**

- Use the formula $m^{\cdot}=\rho\cdot A\cdot v$
- ρ= density of the coolant (kg/m³)
- A = cross-sectional area of the pipe (m²)
- v = velocity of the coolant (m/s)

4. **Calculate the required pipe diameter:**

- Rearrange the equation for area: $A=\frac{m^{\cdot}}{\rho\cdot v}$
- For a circular pipe: $A=\pi\left(\frac{d}{2}\right)^2$
- Solve for d:$d=2\cdot\sqrt{\frac{A}{\pi}}$

1. **Assumptions:**
- Coolant: Water
- Specific heat capacity of water (cp): 4186 J/kg·K
- Temperature difference (ΔT): 40 K (from 80°C to 40°C)
- Density of water (ρ): 1000 kg/m^3
- Pump Specification: 2L/min
- Diameter of the pipe: 6mm

2. **To Find the Velocity of the Coolant using the mass flow rate**
- $v = \frac{4\times Q}{\pi\times d^2}$
- $\frac{3.33\times10^{-5}m^3/s}{2.8274\times10^{-5}m^2} = 1.179\mathrm{m/s}$

3. **To find the Heat Transfer rate**
- $Q=m^{\cdot}\cdot cp\cdot\Delta T$
- m=ρ×V=0.333kg/s
- c_p= 4186j/kg˚C
- Q=0.333×4186×40=5579.14W

4. **Calculate the mass flow rate ($m^{\cdot}$):**

$m^{\cdot} = \frac{Q}{cp\cdot\Delta T} = \frac{5579.14}{4186\cdot 40} = 0.0333$kg/s

5. Calculate the cross-sectional area (A):

$A = \frac{\rho}{vm^{\cdot}} = \frac{0.0333}{1000*1} = 3.33\times10^{-5}$ m^2

6. Calculate the pipe diameter (d):

$d=2\times\sqrt{\frac{A}{\pi}} = 2\times\sqrt{\frac{3.33\times10-5}{\pi}} = 0.00651\mathrm{m} = 6.51\mathrm{mm}$

7.2 Calculation of Heat Exchanger

Choosing an appropriate heat exchanger involves several steps and calculations, based on the information and requirements provided. Here's how you can proceed using the previous calculations:

- **Heat Transfer Rate (Q):**
  From previous calculations, we have the heat transfer rate Q=5579.14 W
- **Temperature Difference (ΔT):**
  The temperature difference is ΔT=40 °C
- **Flow Rate and Properties of Coolant:**
  Volumetric flow rate $V^{\cdot}$=2 L/min˙=3.3333×10−5 m^3/s

The density of water ρ=1000 kg/m^3

Specific heat capacity of water cp=4186 J/kg\°C.

- **Heat Exchanger Selection Criteria:**

1. Type: Shell and tube, plate, or air-cooled heat exchanger. Selection depends on the application, space, and budget.
2. Material: Based on the coolant and the operating environment. Common materials include stainless steel, copper, and aluminium.
3. Size: Determined by the required heat transfer area.

Calculate Log Mean Temperature Difference (LMTD): The LMTD method is used for sizing heat exchangers. For a counter flow heat exchanger:

$\Delta T_1 = T_{\text{hot, in}} - T_{\text{cold, out}}$

$\Delta T_2 = T_{\text{hot, out}} - T_{\text{cold, in}}$

$\Delta Tm = \frac{\Delta T1 - \Delta T2}{ln(\frac{\Delta T1}{\Delta T2})}$

- Assume hot fluid enters at 80°C and exits at 60°C.
- Assume cold fluid enters at 60°C and exits at 80°C.

$\Delta T1 = 80 - 60 = 20$ °C

$\Delta T2 = 80 - 60 = 20$ °C

$\Delta Tm = 20^\circ C$

Calculate Heat Transfer Area (A):

The heat transfer rate equation is:

$Q = U \cdot A \cdot \Delta Tm$

Where:

- Q = 5579.14 W (heat transfer rate)
- U = Overall heat transfer coefficient (W/m²·°C). This value depends on the specific heat exchanger type and construction. Let's assume U=500 W/m²\°C (a typical value for water-water heat exchangers).

Rearranging for A

$A = \frac{Q}{U \times \Delta \text{Tm}}$

$A = \frac{5579.14}{500 \times 20} = 0.5579 m^2$

Summary of Heat Exchanger Specifications:

- Type: tube and fin-type heat exchanger for compactness
- Material: Aluminium (commonly used for water applications).
- Required Heat Transfer Area: 0.5579 m²
- Overall Heat Transfer Coefficient: Assumed as 500 W/m²·°C
- Temperature Program: Hot fluid: 80°C to 40°C, Cold fluid: 20°C to 60°C
- Flow Rates: 2 L/min

Area calculation of the used Heat exchanger:

Given Details:

- Core dimensions: 18 cm (height) x 4 cm (width)
- Core thickness: 3 cm
- Fin details: Fins spaced at around 1.5 mm intervals
- Fin height: 1 cm
- Number of tubes: 5 tubes
- Tube perimeter: 6 cm

1. Core Surface Area (excluding fins):

Front and Back Surface Area=2×(18 cm×4 cm)=2×72 cm^2=144cm^2

Side Surface Area=2×(18 cm×3 cm+4 cm×3 cm)=2×(54 cm^2+12 cm^2)=2×66 cm^2= 132 cm^2

Top and Bottom Surface Area=2× (4 cm×3 cm)=2×12 cm^2=24 cm^2

Total Core Surface Area=144 cm^2+132 cm^2+24 cm^2=300 cm^2

2. Fin Surface Area:

Each fin adds surface area on both sides: Fin Surface Area per Fin=2× (18 cm×1 cm) =36 cm^2
Total Number of Fins=18 cm0.15 cm=120 Total Fin Surface Area=120×36 cm^2=4320 cm^2

3. Tube Surface Area:

Tube Surface Area per Tube=Perimeter×Length=6 cm×18 cm=108 cm2
Total Tube Surface Area=5×108 cm2=540 cm2

4. Total Effective Surface Area:

Total Effective Surface Area=Core Surface Area+Fin Surface Area+Tube Surface Area
Tube Surface Area =300 cm2+4320 cm2+540 cm2=5160 cm^2

8. RESULTS AND DISCUSSION

The result of a Battery Thermal Management System (BTMS) project is that effectively managing and controlling the temperature of a battery system. Ensured that the batteries operate within a safe temperature range, optimizing their performance, efficiency, and lifespan. Some of the Results are mentioned below:

1. **Enhanced Safety:** A well-designed BTMS that prevents the battery from overheating, reducing the risk of thermal runaway and potential safety hazards such as fires or explosions.
2. **Extended Battery Life:** Consistently operating batteries within a specified temperature range can contribute to a longer lifespan, reducing the need for frequent replacements and the overall cost of ownership.
3. **Cost-Effective Design:** Developing a cost-effective BTMS that balances the need for efficient thermal management with the economic constraints of the project is a key outcome. This includes considerations for materials, components, and manufacturing processes.

9. CONCLUSIONS

The development and implementation of a Battery Thermal Management System (BTMS) using liquid cooling technology for electric vehicles (EVs) and energy storage systems (ESS) offer numerous benefits and present various considerations. This conclusion summarizes the key findings, benefits, challenges, and future outlook of the project.

Key Findings:

1. **Enhanced Thermal Regulation**:
- Liquid cooling significantly improves the thermal regulation of battery packs compared to air cooling. This results in more uniform temperature distribution across battery cells, reducing thermal gradients that can lead to cell degradation.

2. **Improved Battery Performance and Longevity**:
- By maintaining optimal operating temperatures, liquid cooling enhances the performance of battery cells, allowing for higher charge and discharge rates. This also extends the overall lifespan of the battery pack by minimizing thermal stress and preventing overheating.

3. **Efficiency in High Power Applications**:
- The liquid cooling system is particularly effective in high-power applications, such as performance EVs and fast-charging scenarios, where air cooling would be insufficient. This ensures that the battery

remains within safe operating temperatures even under high load conditions.

4. **Design and Integration Considerations**:

- The design of the liquid cooling system, including the selection of coolant, heat exchangers, and flow channels, is critical to achieving optimal thermal management. Proper integration with the battery pack design is essential to maximize cooling efficiency and minimize weight and volume.

Benefits:

1. **Thermal Uniformity**:

- Liquid cooling provides superior thermal uniformity across the battery pack, preventing hotspots and ensuring consistent cell performance.

2. **Scalability**:

- Liquid cooling systems can be scaled to accommodate different battery pack sizes and configurations, making them versatile for various types of EVs and ESS applications.

3. **Noise Reduction**:

- Liquid cooling systems tend to be quieter than air cooling systems, which often require high-speed fans, thereby contributing to a more pleasant user experience.

Challenges:

1. **Complexity and Cost**:

- Liquid cooling systems are more complex and expensive to design, manufacture, and maintain compared to air cooling systems. This includes costs associated with pumps, heat exchangers, and potential leaks.

2. **Weight and Packaging**:

- The addition of liquid cooling components increases the weight and packaging complexity of the battery pack, which can affect the vehicle's overall performance and design.

3. **Coolant Selection**:

- The choice of coolant is crucial. It must have excellent thermal properties, be non-conductive, and remain stable over a wide range of temperatures. Ensuring compatibility with battery materials to prevent corrosion or chemical reactions is also vital.

Future Outlook:

1. **Advancements in Coolant Technologies**:

- Research into advanced coolants with better thermal properties and lower environmental impact will continue to enhance the performance and safety of liquid cooling systems.

2. **Integration with Advanced Battery Management Systems**:

- Combining liquid cooling with sophisticated battery management systems (BMS) will optimize thermal control, energy efficiency, and safety, particularly in autonomous and connected vehicles.

3. **Adoption in Broader Applications**:

- As the technology matures, liquid cooling for BTMS will likely expand beyond automotive applications into other areas such as aviation, marine, and grid energy storage, driven by the increasing demand for efficient and reliable energy storage solutions.

REFERENCES

1. https://www.mdpi.com/2313-0105/9/1/44
2. https://www.researchgate.net/publication/322838542_Study_on_the_thermal_interaction_and_heat_dissipation_of_cylindrical_Lithium-Ion_Battery_cells

3. https://mdpi-res.com/d_attachment/energies/energies-14-06196/article_deploy/energies-14-06196-v2.pdf?version=1632907786
4. https://publications.lib.chalmers.se/records/fulltext/200046/200046.pdf
5. Yuqi Huang , Shun Wang , Yiji Lu , Rui Huang , Xiaoli Yu, Department of Energy Engineering, Zhejiang University, Hangzhou, 310027, Zhejiang, China https://www.researchgate.net/publication/342884655_Study_on_a_liquid_cooling-based_battery_thermal_management_system_considering_transient_regime_pertaining
6. Chuanwei Zhang, Jing Huang, Weixin Sun, Xusheng Xu and Yikun Li, School of Mechanical Engineering, Xi'an University of Science and Technology, Xi'an 710054, China https://doi.org/10.3390/wevj13040068
7. Jiahao Liu, Hao Chen, Silu Huang, Yu Jiao and Mingyi Chen, College of Ocean Science and Engineering, Shanghai Maritime University, Shanghai 201306, Chinahttps://doi.org/10.3390/batteries9080400
8. Rui Zhou, Yumei Chen, Jiawen Zhang and Pan Guo, College of Physics and Electronic Engineering, Chongqing Normal University, Chongqing 401331, China. https://pubs.rsc.org/en/content/articlelanding/2023/ma/d3ma00299c
9. Ping Fu, Lan Zhao, Xuguang Wang, Jian Sun and Zhicheng Xin, School of Civil and Architectural Engineering, Nanjing Tech University Pujiang Institute, Nanjing 210000, China https://www.mdpi.com/2227-9717/11/12/3450
10. Muhammad Nizam, Mufti Reza, Aulia Putra Department of Electrical Engineering, Faculty of Engineering, Universitas Sebelas Maret Surakarta, Indonesia https://ijpeds.iaescore.com/index.php/IJPEDS/article/view/22506/14469
11. Maokun Xiong, Ningbo Wang, Wei Li, Akhil Garg and Liang Gao, College of Mechanical and Vehicle Engineering, Chongqing University, Chongqing 400044, China https://www.mdpi.com/2313-0105/9/1/44