# A Review on Liquid Cooling for EV Battery

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*Abstract*— **With increasing concerns about carbon emissions and the resulting climate impacts, Li-ion batteries have become one of the most attractive energy sources, especially in the transportation sector. For Li-ion batteries, an effective thermal management system is essential to ensure high-efficiency operation, avoid capacity degradation, and eliminate safety issues. Thermal management systems based on heat pipes can achieve excellent cooling performance in limited space and thus have been widely used for the temperature control of Li-ion batteries. In this paper, the thermal management systems of Li-ion batteries based on four types of heat pipes, i.e., flat single channel heat pipes, oscillating heat pipes, flexible heat pipes, and micro channel heat pipes, are comprehensively reviewed based on the studies in the past 20 years. The effects of different influencing factors on the cooling performance and thermal runaway behaviour of Li- ion batteries are thoroughly discussed in order to provide an in-depth understanding for researchers and engineers. It is concluded that for all types of thermal management systems based on heat pipes, water spray cooling could achieve better cooling performance than forced air cooling and water bath cooling, while its energy consumption is obviously smaller than forced air cooling. For thermal management systems based on oscillating heat pipes, improved heat transfer characteristics could be achieved by increasing the number of turns, using a relatively larger inner hydraulic diameter and using a length ratio between the evaporator and condenser higher than 1.0. Heat pipes fabricated by flexible materials suffer from permeation of non-condensable gases from ambient and leakage of working fluid. These issues could be partly resolved by adding thermal visa filled with metallic materials and covering the sealing part with indium coating or designing a multi layered structure with metallic materials in it. Moreover, the limitations and future trends of Li-ion battery thermal management systems based on heat pipes are presented. It is pointed out that the thermal runaway behavior and heating performance of battery thermal management systems based on heat pipes should be further elaborated. The analysis of this paper could provide valuable support for future investigations on Li-ion battery thermal management systems based on heat pipes; it could also guide the choice and design of Li-ion battery thermal management systems based on heat pipes in commercial use.**

***Keywords—:*** ***ICEV, EV,LIB,PCM***

## I. INTRODUCTION

The growing demand for carbon neutrality and zero-emission transportation has accelerated the global shift from Internal Combustion Engine Vehicles (ICEVs) to Electric Vehicles (EVs). EVs are considered a sustainable solution to reduce greenhouse gas emissions, fossil fuel dependency, and environmental pollution. According to global EV trends, the adoption of electric vehicles has increased significantly in recent years due to improvements in battery technology, vehicle efficiency, and charging infrastructure. Among various energy storage technologies, Lithium-Ion Batteries (LIBs) are widely used in EVs because of their high energy density, long cycle life, lightweight structure, low self-discharge rate, and high operating voltage. Despite these advantages, thermal safety remains one of the major challenges in lithium-ion battery applications. During charging and discharging processes, batteries generate heat due to internal resistance, electrochemical reactions, and polarization effects. If this heat is not dissipated properly, battery temperature rises continuously, leading to reduced efficiency, shorter battery life, and serious safety hazards. Lithium-ion batteries operate efficiently within a limited temperature range of approximately 15°C to 40°C. When battery temperature exceeds 50°C, performance degradation begins, and battery life decreases significantly. At temperatures above 70°C, thermal runaway may occur, resulting in fire, explosion, toxic gas emission, and irreversible battery damage. Therefore, maintaining battery temperature within the safe operating range is critical for EV performance, reliability, and passenger safety. To overcome these challenges, an effective Battery Thermal Management System (BTMS) is required. A BTMS controls battery temperature by dissipating excess heat and maintaining temperature uniformity among battery cells. Several cooling methods are commonly used in EV battery systems, including: Air Cooling: Simple, low-cost, and easy to maintain, but offers limited heat dissipation and poor temperature uniformity for high-power battery packs. Liquid Cooling: Uses coolant circulation through cooling channels or plates for efficient heat removal. It provides better cooling performance and temperature uniformity than air cooling. Phase Change Material (PCM) Cooling: Absorbs heat through latent heat storage during phase transition, but suffers from low thermal conductivity and volume expansion issues. Heat Pipe Cooling: Offers compact design and passive cooling capability, but involves higher complexity and limited practical large-scale implementation. Among these methods, liquid cooling has emerged as one of the most effective cooling techniques for EV battery packs due to its high heat transfer coefficient, compactness, and ability to manage high heat loads during fast charging and high-power operation.

In liquid cooling systems, coolant is circulated through pipes, channels, or cooling plates placed in contact 9 with battery modules. The coolant absorbs heat generated by the battery cells and transfers it to a radiator or heat exchanger, where the heat is dissipated into the surroundings. This process maintains battery temperature within the desired range and improves overall system efficiency. The increasing demand for fast charging in EVs creates an additional thermal challenge. High charging rates generate large amounts of heat in a short duration, making traditional air cooling insufficient. Liquid cooling systems are better suited for such applications because they can remove heat rapidly and prevent localized overheating. Apart from battery applications, liquid cooling is also widely used in EV power electronics, such as inverters, onboard chargers, and intelligent power modules (IPMs), where thermal management is essential for maintaining device efficiency, reliability, and compactness. Efficient cooling of these components contributes to higher power density and improved vehicle performance. The objective of this project is to design and develop a Liquid Cooling System for EV Battery Packs capable of maintaining battery temperature within the safe operating range. The system consists of components such as a coolant pump, cooling pipes, radiator/heat exchanger, temperature sensors, and control system. The temperature sensor continuously monitors battery temperature, and when the temperature exceeds the preset limit, the cooling system activates automatically. Once the battery temperature falls below the set value, the system turns off to optimize energy consumption. This project aims to improve battery safety, efficiency, lifespan, and thermal stability while demonstrating an effective thermal management solution for modern electric vehicles.

## II. LITERATURE SURVEY.

(Paper 1) An Innovative Additively Manufactured Design Concept of a Dual-Sided Cooling System for SiC Automotive Inverters" (Nov 2024): - This paper presents a novel approach to improving the thermal management of silicon carbide (SiC) automotive inverters. The researchers propose using additive manufacturing (3D metal printing) to develop a dual-sided cooling system capable of efficiently dissipating heat from both sides of the inverter module. The study highlights the limitations of conventional cooling designs, which often involve bulky structures and complex assembly processes. To overcome these challenges, the authors employ advanced 3D printing techniques to fabricate a compact, lightweight, single-piece cold plate that enhances both structural integrity and manufacturing efficiency. The dual-sided cooling design demonstrates significant improvements in thermal performance, power density, and reliability of SiC devices, especially under high operating loads. Both simulation and experimental results confirm uniform temperature distribution and effective heat removal from critical components.

(Paper 2) A Bidirectional Liquid-Cooled GaN-Based AC/DC Flying Capacitor Multi-Level Converter with Integrated Startup and Additively Manufactured Cold-Plate for Electric Vehicle Charging :- This paper introduces a highly efficient and compact power conversion system designed for modern electric vehicle (EV) charging applications. The proposed converter utilizes Gallium Nitride (GaN) devices, which offer high switching frequencies and low power losses, leading to enhanced overall performance. The system adopts a flying capacitor multi-level (FCML) topology, providing smoother voltage transitions, reduced electromagnetic interference (EMI), and improved power quality. Its bidirectional design supports both charging and discharging operations, enabling vehicle-to-grid (V2G) functionality. A key innovation of the study is the integration of a liquid-cooled cold plate fabricated using additive manufacturing (3D metal printing). This design ensures superior thermal management while maintaining a lightweight and compact structure. Through simulation and experimental validation, the researchers demonstrate the converter's high efficiency, thermal stability, and reliable performance under varying load conditions.

(Paper 3) Reduced-Order Thermal Modeling of Liquid-Cooled Lithium-Ion Battery Pack for EVs and HEVs" (Jan 2017) :- This paper presents the development and validation of a simplified yet accurate thermal model for 11 lithium-ion battery packs used in electric vehicles (EVs) and hybrid electric vehicles (HEVs). The proposed reduced-order model effectively captures the essential thermal behavior of the battery system while significantly reducing computational complexity. The model accounts for the influences of liquid cooling flow rate, coolant temperature, and heat generation during charging and discharging cycles. Simulation results are compared with experimental data, confirming the model's accuracy and reliability. By reducing computational demand, the model enables faster simulations, making it suitable for real-time thermal management and control system integration. It accurately predicts temperature distribution and transient thermal behavior of the battery pack under various dynamic operating conditions. The study emphasizes the importance of efficient liquid cooling system design to ensure battery safety, thermal stability, and longer service life. Overall, the research provides a valuable and practical tool for thermal optimization and performance enhancement in next-generation EV and HEV battery systems.

(Paper 4) Energy Savings Achievable Through Liquid Cooling: A Rack Level Case Study" (Feb 2010):-This paper presents a comprehensive analysis of energy-efficient thermal management in data centers through the implementation of liquid cooling technology. The authors develop a thermo-fluid-based model to accurately predict energy utilization and heat transfer behavior within a data center rack. The model is applied to a single rack system, which serves as an experimental platform for validation and performance assessment. The study compares liquid cooling with traditional air-cooling methods, demonstrating notable improvements in cooling efficiency and energy savings. The results reveal that liquid cooling significantly reduces power consumption and thermal resistance of electronic components. The research further investigates the effects of coolant flow rate, inlet temperature, and heat load distribution on system performance. Through combined simulation and experimental evaluation, the authors confirm that liquid cooling achieves higher reliability, lower operational costs, and improved temperature uniformity.

(Paper 5) Cooling System Design and Thermal Analysis of an Electric Vehicle's In-Wheel PMSM" (Oct 2016):- This paper presents the design and analysis of a liquid cooling system for a high-power Permanent Magnet Synchronous Motor (PMSM) used in in-wheel electric vehicle (EV) applications. The study focuses on controlling the heat generated by the stator windings and rotor magnets during high-load operation to maintain optimal motor performance. A detailed thermal analysis, combining computational fluid dynamics (CFD) simulations and experimental validation, is performed to evaluate temperature distribution and cooling efficiency. The results show that the liquid cooling system effectively reduces motor temperature rise, leading to improved efficiency, torque output, and component lifespan. A comparison with conventional air-cooling methods highlights significant gains in thermal stability, performance consistency, and reliability.

(Paper6) Thermal Management of Lithium-Ion Battery Pack with Liquid Cooling" (Feb 2015):- This paper highlights the importance of effective thermal management in improving the performance, safety, and lifespan of lithium-ion battery packs used in electric vehicles (EVs). The study addresses key challenges such as high battery cost, limited driving range, safety concerns, and reduced cycle life, which are often linked to uneven temperature distribution within battery modules. To mitigate these issues, the authors propose a liquid cooling system capable of maintaining battery temperature within an optimal operating range during both charging and discharging processes. Through numerical simulations and experimental analysis, the paper evaluates the influence of coolant flow rate, inlet temperature, and cooling channel geometry on the system's thermal performance. The results demonstrate that liquid cooling provides significant improvements in temperature uniformity, thermal stability, and overall energy efficiency compared to conventional air cooling methods. Furthermore, effective thermal control helps prevent thermal runaway, thereby enhancing battery safety and service life.

(Paper7) Investigations of Li-Ion Battery Thermal Management Systems Based on Heat Pipes" (Oct 2015):- This paper provides a comprehensive review of various heat pipe-based thermal management systems developed for lithium-ion batteries. It examines multiple design configurations including flat single-channel heat pipes, oscillating heat pipes, flexible heat pipes, and microchannel heat pipes—each offering distinct advantages for efficient heat dissipation in battery modules. The study investigates how geometric parameters, cooling configurations, working fluid selection, and filling ratios influence the thermal performance and temperature uniformity of battery packs. It emphasizes that heat pipes offer passive, lightweight, and highly efficient cooling solutions suitable for a wide range of operating conditions. The review further discusses the capability of heat pipe systems to reduce thermal runaway risks and enhance battery safety and reliability. Comparative analyses reveal that oscillating and microchannel heat pipes deliver superior heat transfer performance and support compact, high-density designs. Finally, the paper identifies ongoing challenges, such as optimal working fluid selection and structural optimization, that must be addressed to maximize system performance. Overall, the study offers valuable insights into advanced passive cooling technologies aimed at improving the thermal stability, safety, and lifespan of lithium-ion batteries for electric vehicle applications.

(Paper8) Practical Limits of Liquid Cooling Electric Vehicle Power Modules" (Aug 2022) :- 13 This paper investigates the thermal performance boundaries of liquid cooling systems used in electric vehicle (EV) power modules (Intelligent Power Modules, IPMs). As semiconductor technology transitions from silicon IGBTs to wide-band gap (WBG) materials such as SiC MOSFETs and GaN HEMTs, the study focuses on the cooling challenges posed by increasing power densities and heat flux levels. The authors develop an analytical model based on the heat equation for a representative IPM heat exchanger (HX) to determine the practical thermal limits of conventional liquid cooling systems. The analysis reveals that traditional HX designs may become inadequate for effectively dissipating the elevated heat generated by next-generation semiconductor devices. To address these challenges, the study highlights the need for enhanced cooling strategies, including micro channel heat exchangers, advanced coolant formulations, and optimized flow path designs. Simulation and experimental results demonstrate that beyond a critical heat flux threshold, coolant performance saturates, limiting further temperature reduction.

(Paper9) Design of Liquid Cooling for High Heat Dissipation Electronic Boards Using CFD" (Jan 2017) This paper presents the design and optimization of a liquid cooling system for high-power electronic boards that experience substantial heat generation during operation. The study employs computational fluid dynamics (CFD) to analyze fluid flow and heat transfer characteristics within the cooling channels, aiming to improve overall thermal performance. The research particularly focuses on microprocessor boards, where conventional air-cooling techniques prove insufficient due to high heat flux and compact design constraints. Several cooling channel geometries are designed and simulated to identify the optimal configuration that maximizes heat dissipation while minimizing pressure drop. The results show that liquid cooling significantly improves temperature uniformity and effectively prevents overheating of critical electronic components. The study also investigates the effects of coolant flow rate, inlet temperature, and channel dimensions on cooling performance. Experimental validation confirms the accuracy of CFD predictions, demonstrating the reliability of the proposed design.

## III. OBJECTIVE

The primary objective of the external liquid cooling system is to maintain the optimal thermal conditions of the battery pack, ensuring efficient operation, extended lifespan, and overall system reliability. The system aims to regulate battery temperature effectively, enhance performance, prevent safety hazards such as thermal runaway, and achieve a balance between cost and operational efficiency. Furthermore, it focuses on improving battery health and maintaining consistent performance under varying load and environmental conditions. Sub-objectives:

Temperature Regulation: Maintain the battery temperature within the optimal range of 20–40°C to ensure safe and efficient operation during charging and discharging cycles.

Increased Efficiency: Improve overall battery performance by enhancing thermal management, which leads to better capacity utilization and longer operational life.

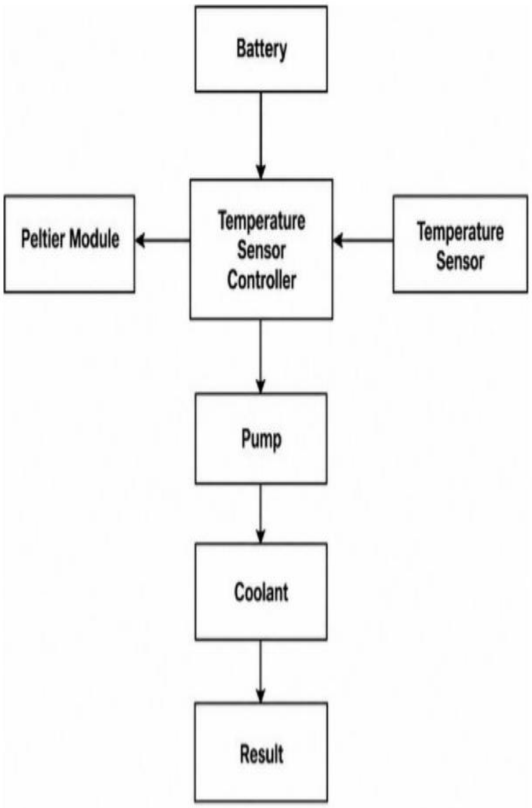
Reduced Thermal Runaway Risk: Minimize the risk of overheating and potential safety hazards by implementing an effective and responsive cooling mechanism.

Cost-Effectiveness: Design a cooling system that is economical in both initial setup and long-term maintenance while ensuring high performance. Reliability: Ensure continuous and stable operation of the cooling system with minimal maintenance requirements and high durability. Improved Battery Health: Reduce degradation rates by maintaining uniform temperature distribution, thereby extending the overall lifespan and performance stability of the battery.

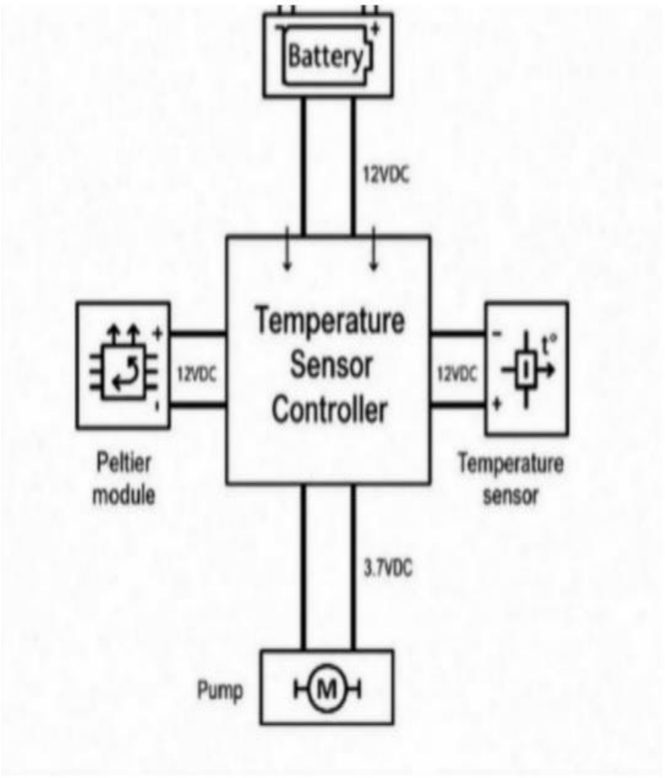
## IV. PROBLEM STATEMENT

The rapid growth of electric vehicles and energy storage systems has increased the demand for efficient battery thermal management. During charging and discharging cycles, batteries generate significant heat, leading to elevated temperatures. Excessive heat can degrade battery materials, reduce efficiency, and shorten the overall lifespan. Uncontrolled temperature rise may also cause thermal runaway, posing serious safety risks. Traditional air-cooling methods often fail to maintain uniform temperature across battery cells. Therefore, an effective liquid cooling system is required to regulate temperature more precisely. 15 The system must maintain optimal operating conditions (20–40°C) for consistent battery performance. It should be designed to minimize thermal gradients and improve energy efficiency. The proposed design must also ensure reliability, low maintenance, and cost-effectiveness. Thus, the problem focuses on developing a robust hardware design for a liquid cooling system that enhances battery safety, efficiency, and longevity

## V. BLOCK DIAGRAM



## VI. CIRCUIT DIAGRAM



## VII. WORKING PRINCIPLE

The liquid cooling system for electric vehicle (EV) batteries is designed to maintain the battery pack within an optimal operating temperature range to improve efficiency, safety, and battery lifespan. Lithium-ion batteries used in EVs are highly sensitive to temperature variations. Excessive heat generation during charging, discharging, and high-load operations can reduce battery performance, accelerate degradation, and even create safety risks such as thermal runaway. The proposed system continuously removes excess heat from the battery pack and maintains uniform temperature distribution across all cells.

1. Heat Generation in Battery Cells During the charging and discharging process, lithium-ion battery cells generate heat due to two major factors: internal resistance losses and electrochemical reactions. When current flows through the battery, resistive heating occurs because of the internal impedance of the cells. Additionally, side chemical reactions inside the cell contribute to temperature rise. Under fast charging, rapid acceleration, or high discharge rates, the amount of generated heat increases significantly. If this heat is not removed effectively, the battery temperature rises beyond the safe operating limit, negatively affecting battery capacity and efficiency.

2. Heat Transfer to Cooling Medium To remove the generated heat, battery modules are placed in contact with cooling plates or liquid channels. These channels are designed in such a way

that coolant can flow close to the battery surface for maximum heat absorption. A thermal interface material (TIM) is used between the battery surface and cooling plate to reduce thermal resistance and improve heat conduction. The generated heat is transferred from the battery cells to the cooling plate and finally into the circulating liquid coolant.

3. Coolant Circulation Process The coolant circulation is maintained using a DC water pump. The pump continuously drives the coolant through pipes, cooling plates, and heat exchangers in a closed-loop system. As the coolant flows through the battery cooling channels, it absorbs thermal energy from the battery pack. Continuous circulation prevents the formation of localized hot spots and ensures that all battery cells remain at nearly the same temperature. This uniform temperature distribution is critical because uneven temperatures can lead to imbalance in battery performance and reduced pack efficiency.

4. Peltier Module-Based Active Cooling In this project, Peltier modules (thermoelectric coolers) are integrated to provide additional active cooling. The Peltier module works on the thermoelectric effect, where heat is transferred from one side of the module to the other when electric current passes through it. The cold side is attached to the cooling plate or coolant chamber, while the hot side is connected to a heat sink and fan arrangement. This setup enhances cooling efficiency by actively reducing coolant temperature whenever battery temperature exceeds the predefined threshold value.

5. Heat Dissipation through Heat Exchanger After absorbing heat from the battery pack, the heated coolant flows to a heat exchanger or radiator section. The heat exchanger transfers the absorbed thermal energy from the coolant to the surrounding air. Fins are used to increase the effective surface area, improving the heat transfer rate. A fan may also be used to force airflow across the heat exchanger for faster cooling. This process lowers the coolant temperature before it reenters the battery cooling loop.

6. Return Flow to Battery Pack Once cooled, the coolant is circulated back to the battery pack through the inlet pipe. This creates a continuous closed-loop cycle of heat absorption, heat rejection, and recirculation. The system ensures that battery temperature remains within the desired operating range of approximately 20°C to 40°C, which is considered ideal for lithium-ion battery performance.

7. Temperature Monitoring System Multiple temperature sensors are installed at different points in the battery pack and coolant path. These sensors continuously monitor battery surface temperature, coolant inlet temperature, and coolant outlet temperature. The sensor data is sent to the microcontroller or control unit for real-time monitoring and decision-making.

8. Control System Operation The control system automatically regulates the cooling process based on temperature feedback. When battery temperature rises above the set limit, the controller activates the pump, Peltier modules, and cooling fan. Once the temperature drops below the desired value, the system automatically switches off or reduces component operation to save energy. This automation improves overall thermal management efficiency and minimizes unnecessary power consumption.

9. Coolant Selection and Properties The coolant used in the system plays a vital role in heat transfer performance. A suitable coolant such as water-glycol mixture is selected because of its high specific heat capacity, thermal conductivity, and anticorrosion properties. The coolant must also provide chemical stability and low freezing point for safe longterm operation.

10. Safety Features To ensure safe operation, the system includes protective mechanisms such as temperature cut-off limits, leak-proof piping connections, and overpressure protection. If abnormal temperature rise or coolant blockage is detected, the control system can trigger an alert or shut down the system to prevent battery damage.

11. Energy Efficiency and Advanced Features In advanced EV battery thermal management systems, recovered heat from the coolant can be reused to preheat batteries in cold environments. This improves startup performance and reduces energy loss. Although optional, such features demonstrate the potential for improving overall EV energy efficiency.

## VIII. COMPONENTS USED

1) A battery is a device that stores chemical energy and converts it into electrical energy when needed Types of Batteries –

• Lithium-ion Battery • Ni - Cd Battery • Zinc Carbon Battery • Alkaline Battery • Ni –MH Battery • Coin Cell Battery • Lead – acid Battery • Sealed Battery

Li-ion Battery

Capacity – 2000 mAh The battery used in the proposed liquid cooling system is a Lithium-Ion rechargeable battery with a capacity of 2000 mAh (milliampere-hour). Battery capacity indicates the amount of electric charge that the battery can store and deliver over time. A 2000 mAh battery is capable of supplying 2000 mA current for one hour, or proportionally lower current for a longer duration depending on the connected load. In this project, the selected battery capacity is suitable for powering low-power electronic components such as the DC water pump, temperature sensors, Peltier module, cooling fan, and control circuit. The compact size, lightweight nature, and rechargeable characteristics make it ideal for experimental and portable thermal management systems.

Voltage – 3.7 V The nominal voltage of the selected Lithium-Ion battery is 3.7 volts. This is the standard operating voltage of a single Li-ion cell. The battery voltage may vary between 4.2 V (fully charged state) and 3.0 V (fully discharged state). The 3.7 V battery is chosen because it provides stable power supply for low-voltage electronic devices used in the project. In practical applications, multiple Li-ion cells can be connected in series or parallel combinations to achieve higher voltage or current requirements.

A Lithium-Ion (Li-ion) battery is a rechargeable energy storage device that stores electrical energy through the movement of lithium ions between two electrodes. It is one of the most widely used battery technologies in modern applications due to its high energy density, long cycle life, low maintenance, and lightweight construction. Lithium-ion batteries are extensively used in various fields such as: Smartphones and laptops Electric vehicles (EVs) Solar energy storage systems Aerospace applications Medical equipment Consumer electronics In electric vehicles, lithium-ion batteries are preferred because they can provide high power output while maintaining compact size and lower weight compared to conventional lead-acid batteries.

A lithium-ion battery mainly consists of four essential components:

1. Anode The anode is generally made of graphite material. During charging, lithium ions move and get stored inside the graphite layers through a process called intercalation. The anode acts as the negative terminal of the battery.
2. Cathode The cathode is commonly made of lithium metal oxides such as: Lithium Cobalt Oxide ($LiCoO_2$) Lithium Iron Phosphate ($LiFePO_4$) Lithium Nickel Manganese Cobalt Oxide (NMC) The cathode acts as the positive terminal and stores lithium ions during battery discharge.
3. Electrolyte The electrolyte is a liquid or gel medium containing lithium salt dissolved in an organic solvent. It enables the movement of lithium ions between anode and cathode while preventing electron flow directly inside the battery.
4. Separator The separator is a thin porous membrane placed between the anode and cathode. It prevents physical contact between the electrodes, avoiding short circuits, while still allowing lithium ions to pass through.

The operation of a lithium-ion battery is based on the movement of lithium ions between the anode and cathode during charging and discharging cycles.

Discharge Cycle When the battery supplies power to a load, it undergoes the discharge process. Lithium ions move from the anode to the cathode through the electrolyte. Electrons released at the anode flow through the external circuit to the connected device, producing electric current. At the cathode, lithium ions combine with electrode material through a chemical reduction reaction. This electron movement powers devices such as pumps, sensors, fans, and control circuits.

Charge Cycle When connected to an external charger, the battery undergoes the charging process. External voltage greater than battery voltage is applied. Lithium ions move back from the cathode to the anode through the electrolyte. Electrons are forced through the external circuit toward the anode. Energy is stored again in chemical form inside the battery. Thus, the battery becomes ready for the next discharge cycle.

2) Temperature Sensor ·

A temperature sensor is a device that measures temperature and converts it into an electrical signal for monitoring or control. Types of temperature sensor • NTC Waterproof Sensors • RTD • Thermocouple • Thermistor

Sensor Used: Waterproof NTC Temperature Sensor Controller Used: W1209 Digital Temperature Controller Module The temperature monitoring system used in this project consists of a Waterproof NTC (Negative Temperature Coefficient) temperature sensor integrated with a W1209 digital temperature controller module. This combination is used to continuously measure battery temperature and automatically control the cooling system components such as the pump, fan, and Peltier module based on the temperature conditions. In the proposed EV battery liquid cooling system, temperature sensing is a critical part of the thermal management process. Since lithium-ion batteries are highly sensitive to overheating, real-time temperature monitoring ensures efficient operation and prevents thermal damage.

An NTC (Negative Temperature Coefficient) thermistor is a type of resistor whose electrical resistance decreases as temperature increases. It is made using semiconductor metal oxide materials such as manganese, nickel, cobalt, or copper oxides. The working principle is based on semiconductor behavior. As temperature rises, more charge carriers become available inside the thermistor material, which increases conductivity and reduces resistance. Similarly, when temperature decreases, the number of charge carriers reduces, causing resistance to increase. The waterproof NTC sensor is enclosed in a stainless steel or waterproof metal probe with insulated wiring. This protective casing makes it suitable for measuring temperature in liquid environments, such as coolant systems, without electrical damage.

3) Digital Temperature Controller Module

Specification Module
Type: Digital Temperature Controller
Operating Voltage: 12V DC
Temperature Range: -50°C to +110°C
Display Type: 3-Digit LED Display Relay
Output: 10A, 220V AC
Control Modes: Heating / Cooling

The Digital Temperature Controller Module is an electronic device used for automatic monitoring and regulation of temperature. It continuously receives temperature data from the connected temperature sensor and displays the measured value on the LED screen. The user can set a desired temperature limit using push buttons provided on the module. 31 When the sensed temperature crosses the preset value, the controller activates or deactivates the relay output. This relay is connected to external devices such as cooling fans, pumps, heaters, or compressors. The module is compact, easy to operate, and suitable for various industrial and domestic temperature control applications. In this project, the Digital Temperature Controller Module is used to control the liquid cooling system of electric vehicle batteries. It ensures that the battery pack operates within a safe temperature range and prevents overheating.

The working principle of the Digital Temperature Controller Module is based on automatic temperature sensing and relay switching. The temperature sensor continuously monitors the battery or coolant temperature. The measured temperature is displayed on the LED display in real time. The user sets a desired temperature limit using push buttons. The controller compares the measured temperature with the preset temperature value. When the temperature rises above the set limit, the relay gets activated and turns ON the cooling system components such as: Water Pump Cooling Fan Peltier Module The cooling system starts circulating coolant through the battery pack and removes excess heat. Once the temperature falls below the desired limit, the relay turns OFF automatically and stops the cooling system. Thus, the controller maintains the battery temperature within the required operating range automatically.

In the proposed Liquid Cooling System for EV Batteries, the Digital Temperature Controller Module plays an important role in maintaining battery temperature. When the battery temperature increases beyond the preset value, the controller automatically activates the cooling pump and fan. After the battery reaches safe temperature conditions, the controller switches OFF the system. This improves battery safety, efficiency, and operational life.

4) Pump

A pump is a mechanical device used to transfer fluids such as water, oil, gases, or chemical liquids from one location to another. In thermal management systems, pumps are mainly used to circulate coolant continuously through the cooling circuit. In the proposed project, a DC Water Pump is used to circulate coolant through the battery cooling channels. The pump ensures continuous coolant flow between the battery pack, cooling chamber, and heat dissipation 35 system. The proper circulation of coolant is essential in battery thermal management systems because it helps absorb excess heat generated by battery cells and transfers it away from the battery pack.

The water pump used in this project works on the principle of a centrifugal pump. A centrifugal pump is a type of dynamic pump that transfers fluid by converting rotational mechanical energy into fluid kinetic energy. The working process is as follows:

1. The pump motor rotates the impeller at high speed.
2. The rotating impeller creates centrifugal force.
3. Due to centrifugal force, coolant moves outward from the center of the impeller toward the outer edges.
4. This movement creates low pressure at the center of the pump.
5. Coolant from the inlet pipe enters the pump due to pressure difference.
6. The pump forces coolant through the outlet pipe toward the battery cooling chamber.
7. Coolant absorbs battery heat and returns back for recirculation. Thus, continuous coolant circulation is maintained in a closed loop system.

In the Liquid Cooling System for EV Batteries, the pump performs the following functions:

1. Circulates coolant through battery cooling pipes. 2. Transfers heated coolant away from the battery pack.
3. Sends coolant toward cooling section or heat exchanger.
4. Maintains uniform temperature distribution throughout the battery system.
5. Prevents battery overheating by ensuring continuous liquid movement. When battery temperature exceeds the preset value, the digital temperature controller automatically activates the pump. After battery temperature reduces below the set temperature, the pump is switched OFF automatically.

The DC water pump is one of the most important components in the proposed EV Battery Liquid Cooling System. It ensures proper circulation of coolant through the battery pack for effective heat removal. Without continuous coolant flow, heat cannot be transferred efficiently, which may result in battery overheating and reduced performance. Therefore, the pump improves battery safety, cooling efficiency, and system reliability.

5) Peltiar module

A Thermoelectric Cooler Module, commonly known as a Peltier Module, is a solid-state electronic device used for heating and cooling applications. It works on the principle of the Peltier Effect, where heat transfer occurs between two different semiconductor materials when electric current passes through them. When DC power is supplied to the module, one side of the module becomes cold while the opposite side becomes hot. The cold side is used for cooling purposes, whereas the hot side is connected to a heat sink and cooling fan for heat dissipation. In this project, the Thermoelectric Cooler Module is used as an active cooling component in the Liquid 38 Cooling System for Electric Vehicle Batteries. It helps reduce battery temperature during charging and discharging conditions and maintains the battery pack within a safe operating temperature range.

Fig. 5.1.5 Peltiar module

The Thermoelectric Cooler Module operates based on the Peltier Effect. The working process is as follows:
1. When DC current passes through the module, electrons move between semiconductor junctions.
2. Due to the Peltier Effect, heat is absorbed on one side of the module and released on the opposite side.
3. The cold side of the module absorbs heat from the battery cooling chamber or coolant system.
4. The hot side releases heat to the surroundings.
5. A heat sink is attached to the hot side to improve heat transfer.
6. A cooling fan is used to remove heat from the heat sink efficiently.
7. The cooled surface helps lower the coolant temperature, which further cools the battery pack. Thus, the module provides continuous active cooling for thermal management.

In the proposed Liquid Cooling System for EV Batteries, the Thermoelectric Cooler Module performs the following functions:
1. Reduces coolant temperature before circulation. 2. Absorbs excess heat from the battery cooling system.
3. Maintains battery temperature within the safe operating range.
4. Improves battery efficiency and thermal stability. 5. Prevents battery overheating during charging and discharging cycles. The module operates automatically when the battery temperature exceeds the preset value.

The Thermoelectric Cooler Module is an important part of the proposed EV Battery Liquid Cooling System. It provides additional active cooling support to the liquid cooling circuit. When battery temperature increases beyond the safe limit, the module helps reduce coolant temperature and improves heat removal efficiency. This ensures battery safety, higher efficiency, longer life span, and better thermal management performance.

6) Aluminum Sheet

Aluminum sheet is a lightweight metallic material widely used in mechanical, electrical, and thermal engineering applications due to its excellent thermal conductivity, corrosion resistance, and high strength-to weight ratio. It is manufactured from aluminum or aluminum alloys and is available in different thicknesses and dimensions depending on application requirements. Aluminum is considered one of the most suitable materials for thermal management systems because it can efficiently transfer heat while maintaining low structural weight. Its corrosion-resistant nature makes it ideal 42 for long-term applications where moisture, coolant exposure, or environmental conditions may affect other metals. In the proposed Liquid Cooling System for Electric Vehicle Batteries, the aluminum sheet is used as the supporting base structure as well as a heat transfer medium. It provides mechanical support for mounting various components such as battery modules, Peltier module, water pump, cooling pipes, heat sink, and fan assembly. Additionally, due to its high thermal conductivity, the aluminum sheet assists in dissipating excess heat generated by battery cells and cooling components.

The aluminum sheet is an important structural and thermal component in the proposed Liquid Cooling System for EV Batteries. It provides a rigid platform for assembling the complete system and improves heat transfer efficiency through passive thermal conduction. By combining lightweight construction with effective heat dissipation properties, the aluminum sheet enhances the reliability, durability, and cooling performance of the system. Its use also reduces overall system weight, which is beneficial for electric vehicle applications

## IX. WORKING

The proposed Liquid Cooling System for Electric Vehicle (EV) Batteries is an intelligent temperaturecontrolled system designed to maintain the battery pack within a safe operating temperature range during charging and discharging conditions. Lithium-ion batteries generate heat because of internal resistance, electrochemical reactions, and continuous current flow. If this generated heat is not controlled effectively, battery efficiency decreases, battery life reduces, and safety risks such as thermal runaway may occur. To overcome these issues, the proposed system uses a combination of a battery power supply, Arduino microcontroller, digital temperature controller, water pump, thermoelectric cooling module (Peltier module), cooling fan, and coolant circulation mechanism to regulate battery temperature automatically. The working of the system begins with the power supply section. A 12V DC battery is used as the main power source for the complete cooling system. In practical applications, if a higher voltage source is available, a buck converter is used to step down the voltage to the required operating level. This regulated voltage is then distributed to all system components, including the Arduino microcontroller, digital temperature controller, relay circuit, water pump, Peltier module, and cooling fan. The power supply section ensures stable and uninterrupted operation of the thermal management system. To continuously monitor battery temperature, a temperature sensor is installed near the battery pack or cooling chamber. In this project, a waterproof NTC temperature sensor is used to measure battery temperature in real time. The sensor continuously detects temperature changes and converts them into corresponding electrical signals. These signals are sent to the digital temperature controller or Arduino input terminal for processing. The measured temperature is simultaneously displayed on the LED display module, allowing the user to monitor the battery temperature continuously. The temperature controller compares the measured temperature with the preset temperature value set by the user. For example, if the user sets the operating temperature limit at 35°C, the controller continuously checks whether the measured battery temperature exceeds this threshold value. As long as the battery temperature remains below the set value, the cooling system remains in OFF condition to save energy. When the battery temperature rises above the preset temperature limit, the controller automatically activates the cooling mechanism. The relay module switches ON the water pump, Peltier module, and cooling fan simultaneously. The water pump starts circulating coolant through the liquid cooling pipes or cooling jacket placed around the battery pack. The coolant may be water or glycol-based liquid, selected for its high thermal conductivity and heat absorption capacity. As the coolant flows through the cooling jacket, it absorbs excess heat generated by the battery cells.

The 47 heated coolant is then directed toward the thermoelectric cooling section. At this stage, the Peltier module plays an important role in further reducing coolant temperature. The Peltier module works on the principle of the Peltier Effect. When DC current passes through the module, one side becomes cold while the opposite side becomes hot. The cold side is placed in contact with the coolant path, allowing it to absorb heat from the coolant and reduce its temperature. The hot side is connected to a heat sink and cooling fan arrangement to dissipate heat into the surrounding environment. After passing through the Peltier cooling section, the cooled coolant is circulated back to the battery cooling chamber. This closed-loop circulation process continuously removes heat from the battery pack and maintains uniform temperature distribution throughout the battery system. By ensuring efficient heat transfer, the system prevents the formation of localized hot spots and improves battery thermal stability. The cooling system continues operating until the battery temperature decreases to a safe operating level. For example, once the battery temperature falls below 30°C, the temperature controller detects the reduced temperature and sends a control signal to deactivate the relay output. As a result, the water pump, Peltier module, and cooling fan are switched OFF automatically. This intelligent control mechanism prevents unnecessary energy consumption and avoids overcooling, which can negatively affect battery performance under certain operating conditions. Thus, the proposed liquid cooling system provides automatic battery temperature regulation by integrating real-time sensing, intelligent control, coolant circulation, and active thermoelectric cooling. The system ensures safe battery operation, improves charging and discharging efficiency, increases battery lifespan, and enhances the overall reliability of electric vehicle battery packs. Due to its compact design, low cost, and automatic operation, the proposed system is highly suitable for battery thermal management applications in electric vehicles and energy storage systems.

## X. FUTURE SCOPE

The future scope of liquid cooling systems for EV (Electric Vehicle) batteries is very promising and is expected to evolve significantly due to the growing demand for electric vehicles, advancements in battery technology, and the increasing focus on thermal management for **safety**, performance, and battery life. Here's a detailed breakdown of the future scope:

1.Integration with Next-Gen Battery Technologies Solid-state batteries, lithium-sulfur, and sodium-ion batteries have different thermal profiles than traditional lithium-ion. Liquid cooling systems will need to adapt to higher thermal loads and tighter space constraints while ensuring uniform temperature distribution.

2.Ultra-Fast Charging Compatibility Fast charging (e.g., 350 kW or higher) significantly increases heat generation. Advanced liquid cooling systems will be critical in preventing thermal runaway and enabling safe fast charging without degrading battery health.

3. Smart Thermal Management Systems Use of AI and ML algorithms for predictive thermal control. Dynamic flow rate adjustment using sensors and actuators for real-time thermal load balancing. Integration with vehicle's Battery Management System (BMS) for optimized performance.

4. Modular and Scalable Designs Scalable cooling solutions that can be customized for: Passenger EVs Commercial vehicles Battery swapping stations Modular battery packs will require modular cooling subsystems, improving maintenance and upgradability.

5. Use of Advanced Coolants Development of non-toxic, high thermal conductivity, and low-viscosity coolants. Introduction

of nanofluids or phase change materials (PCMs) for enhanced heat absorption and dissipation.

6. Sustainability and Energy Efficiency Focus on energy-efficient pumps and low-power electronics in the cooling loop. Use of recyclable materials in cooling plates and tubing. Integration with vehicle waste heat recovery systems.

7. Compact and Lightweight Designs Innovations in microchannel heat exchangers, integrated cold plates, and multi-layer cooling plates. Emphasis on reducing weight and volume to increase EV range and efficiency.

8. Simulation and Digital Twin Technology Use of CFD (Computational Fluid Dynamics) and digital twins for design optimization and real-time monitoring. Simulated testing environments to accelerate development cycles and improve reliability.

9. Applications Beyond Vehicles Liquid-cooled battery systems will be key in: Grid-scale energy storage Aerospace and drones Marine and military electric vehicles.

## XI. RESULTS

### BEFORE USING LIQUID COOLING SYSTEM

| SR. NO. | BATTERY TEMPERATURE | OUTPUT VOLTAGE | TIME |
|---|---|---|---|
| 1. | 29 | 12.10 | 10 min |
| 2. | 30 | 11.80 | 20 min |
| 3. | 33 | 11.48 | 30 min |
| 4. | 37 | 10.89 | 40 min |
| 5. | 39 | 10.68 | 50 min |

### AFTER USING LIQUID COOLING SYSTEM

| SR. NO. | BATTERY TEMPERATURE | OUTPUT VOLTAGE | TIME |
|---|---|---|---|
| 1. | 25 | 13.05 | 10 min |
| 2. | 26 | 12.82 | 20 min |
| 3. | 28 | 12.23 | 30 min |
| 4. | 30 | 12.08 | 40 min |
| 5. | 31 | 11.97 | 50 min |

## XII. CONCLUSION

Liquid cooling system for battery in electric vehicles (EV’s) have contributed most to ensure safe, efficient, and reliable operation and riding experiences. By using Liquid cooling system for batteries in EV the temperature management is achieved very efficiently, which enhances battery life span up to 50% by improving charging efficiency by up to 20%, This results in increase in overall range of EV by up to 15%. By this system Thermal runaway risk have been efficiently reduced which squirts the battery for high power charging capability and optimized battery performance in extreme Temperature is achieved successfully.

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