

# Design and Development of a Battery Thermal Management System (BTMS) for an Electric Two-Wheeler

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**Abstract - Battery Thermal Management System (BTMS) plays a crucial role in maintaining the performance, safety, and lifespan of lithium-ion batteries used in electric vehicles. Electric two-wheelers operate under compact packaging and high ambient temperature conditions, especially in countries like India, making thermal management a critical engineering challenge. This research paper presents the design and development of an automated liquid-based Battery Thermal Management System for an electric two-wheeler. The system uses aluminum cooling blocks, a closed-loop coolant circulation mechanism, temperature sensors, and a microcontroller-based control system to maintain battery temperature within a safe operating range. The proposed system demonstrates effective heat removal, energy efficiency, and real-time temperature monitoring. Experimental analysis shows that the system can dissipate heat loads effectively while consuming relatively low power, making it suitable for low-cost electric mobility solutions.**

**Keywords:** Battery Thermal Management System, Electric Two-Wheeler, Liquid Cooling, Temperature Monitoring, ESP32, Lithium-ion Battery, Automation, Thermal Control.

## I. INTRODUCTION

The rapid growth of electric vehicles has increased the demand for efficient energy storage systems, particularly lithium-ion batteries. These batteries are widely used due to their high energy density, long cycle life, and fast charging capability. However, lithium-ion batteries generate significant heat during charging and discharging cycles due to internal resistance and electrochemical reactions. Excessive heat accumulation can lead to reduced battery efficiency, accelerated degradation, and safety hazards such as thermal runaway.

In electric two-wheelers, the battery pack is usually installed in a confined enclosure with limited airflow. Under high ambient temperatures, such as those commonly experienced in tropical regions, the battery temperature may exceed the recommended operating range of 20°C to 40°C. Conventional passive cooling systems are often insufficient to

dissipate heat under heavy load conditions, resulting in performance loss and reduced battery lifespan.

To address this problem, an active Battery Thermal Management System (BTMS) is required. Liquid cooling is considered one of the most efficient methods for heat removal due to the high thermal conductivity and heat capacity of liquids compared to air. The integration of automation and temperature-based control logic further enhances system efficiency by activating cooling components only when required.

This research focuses on designing and developing a cost-effective automated liquid-based BTMS suitable for electric two-wheeler applications. The system aims to maintain battery temperature within a safe range, improve battery life, and enhance operational safety.

However, the authors name can be used along with the reference number in the running text. The order of reference in the running text should match with the list of references at the end of the paper.

## II. LITERATURE REVIEW

### 2.1 Battery thermal management in EVs and HEVs

Pesaran, A. A. (2001). Battery thermal management in EVs and HEVs: Issues and solutions. Advanced Automotive Battery Conference.

This foundational paper by Ahmad Pesaran at the National Renewable Energy Laboratory established the basic framework for understanding thermal management in electric and hybrid vehicle batteries. Pesaran identified that battery performance, life, and safety are all strongly dependent on temperature, and that both overheating and excessive cooling are harmful. The paper outlined the need for active thermal management systems that maintain cell temperatures within a narrow optimal band. It compared air cooling, liquid cooling, and phase change material approaches, concluding that liquid cooling offers the best balance of thermal efficiency and packaging flexibility. This work is widely cited as the starting point for most subsequent research in battery thermal

management and directly supports the liquid cooling approach adopted in this project.

## **2.2 Thermal investigation of lithium-ion battery**

Wang, T., Tseng, K. J., Zhao, J., and Wei, Z. (2014). Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies. *Applied Energy*, 134, 229-238.

This study investigated how cell arrangement and forced air cooling affect temperature distribution across a lithium-ion battery module. The researchers found that uniform airflow across all cell significantly reduced the maximum temperature and temperature differential within the pack. However, the paper also identified the limitations of air cooling under high discharge rates, where heat generation exceeded the capacity of forced air to dissipate it effectively. The findings are relevant to this project as they justify the decision to move beyond air-only cooling and adopt a liquid-based approach, particularly for scenarios involving sustained load and high ambient temperatures typical of Indian operating conditions.

## **2.3 Experimental study of heat pipe thermal management system**

Zhao, R., Gu, J., and Liu, J. (2015). An experimental study of heat pipe thermal management system with wet cooling method for lithium ion batteries. *Journal of Power Sources*, 273, 1089-1097.

This paper explored the use of heat pipes combined with wet cooling for lithium-ion battery thermal management. The experimental results demonstrated that direct contact between the cooling medium and the battery surface, or a thermally conductive interface, produced significantly better heat absorption than indirect methods. The study recorded that maintaining coolant flow at moderate rates was sufficient to keep battery temperatures within safe limits during standard discharge cycles. The concept of using a conductive interface block between the battery and the coolant channel, which is central to this project through the use of aluminum cooling blocks, is supported by the findings of this research.

## **2.4 Review of power battery thermal energy management**

Rao, Z., and Wang, S. (2011). A review of power battery thermal energy management. *Renewable and Sustainable Energy Reviews*, 15(9), 4554-4571.

This comprehensive review paper examined all major categories of battery thermal management including air cooling, liquid cooling, heat pipe systems, and phase change materials. The authors analysed each method in terms of thermal performance, complexity, cost, and suitability for

different applications. Liquid cooling was identified as the most effective active method for high-power applications, with the ability to manage heat loads that are simply beyond the capacity of air-based systems. The review also highlighted that automated control of cooling systems based on real-time temperature feedback is essential for achieving both performance and energy efficiency. This directly aligns with the ESP32-based automated control logic implemented in this project.

## **2.5 Electro-thermal analysis and integration issues of lithium ion battery for electric vehicles**

Saw, L. H., Ye, Y., and Tay, A. A. O. (2016). Electro-thermal analysis and integration issues of lithium ion battery for electric vehicles. *Applied Energy*, 131, 97-107.

This paper presented a coupled electro-thermal model for lithium-ion batteries in electric vehicle applications. The researchers demonstrated that temperature rise during high discharge rates is non-linear and can escalate rapidly if cooling is not initiated early enough. One of the key findings was that delaying the activation of cooling by even a few minutes under peak load conditions leads to disproportionately higher peak temperatures. This finding directly supports the staged threshold-based activation logic used in this project, where the first cooling stage is triggered at 30 degrees Celsius, well before temperatures reach dangerous levels, allowing the system to intervene early and prevent escalation.

## **III. METHODOLOGY**

The methodology adopted in this project involves designing a closed-loop liquid cooling system integrated with temperature sensing and automated control logic. The system consists of cooling blocks, coolant pumps, a radiator, temperature sensors, and a microcontroller unit.

### **3.1 Cooling Method Selection**

Different cooling methods such as passive cooling, air cooling, phase change material cooling, and liquid cooling were evaluated based on performance, cost, and complexity. Liquid cooling was selected due to its superior heat transfer capability and reliability in high-temperature environments.

### **3.2 System Components**

The main components used in the proposed BTMS include:

- Aluminum cooling blocks
- Water coolant reservoir
- DC water pumps
- Radiator with cooling fan
- ESP32 microcontroller

- DS18B20 temperature sensors
- Relay modules
- Power supply unit

### 3.3 Control Strategy

A rule-based temperature threshold control method is implemented in the system. The microcontroller continuously monitors temperature readings and activates cooling components in stages based on predefined thresholds:

- Stage 1: Heatsink fans activate at 30°C
- Stage 2: Water pumps activate at 35°C
- Stage 3: Radiator fan activates at 37°C

This staged operation ensures efficient energy usage and prevents unnecessary power consumption.

## IV. SYSTEM DESIGN AND WORKING PRINCIPLE

The proposed Battery Thermal Management System is designed to remove heat from the battery using a liquid cooling mechanism. The system operates as follows:

1. Heat generated by the battery is transferred to aluminum cooling blocks through conduction.
2. Coolant circulating through the cooling blocks absorbs the heat.
3. The heated coolant flows to the radiator through flexible tubing.
4. A cooling fan dissipates heat from the radiator into the surrounding air.
5. The cooled coolant returns to the reservoir and recirculates through the system.

Temperature sensors are placed at critical locations such as the battery surface, coolant tank, radiator, and ambient environment. These sensors provide real-time temperature data to the microcontroller, which controls the operation of pumps and fans through relay modules.

The system is powered using a 12V DC power supply, and all temperature readings can be monitored through a web-based dashboard using Wi-Fi connectivity.

## V. DESIGN CALCULATIONS

### A. Heat Load Calculation

Heat generated by battery simulator:  $Q = 100 \text{ W}$

### B. Mass Flow Rate of Coolant

Density of water =  $1000 \text{ kg/m}^3$

Flow rate =  $0.00002 \text{ m}^3/\text{s}$

Mass flow rate:  $m = 0.02 \text{ kg/s}$

### C. Heat Absorption by Coolant

Specific heat capacity of water =  $4186 \text{ J/kg}^\circ\text{C}$

Temperature rise of coolant =  $2^\circ\text{C}$

Heat absorbed:

$$Q = 0.02 \times 4186 \times 2$$

$$Q = 167.44 \text{ W}$$

Since the heat absorption capacity is greater than the heat generated, the cooling system is capable of handling the thermal load effectively.

### D. System Power Consumption

- ESP32 microcontroller =  $0.5 \text{ W}$
- Water pumps =  $12 \text{ W}$
- Cooling fans =  $15.6 \text{ W}$
- Relay modules =  $0.5 \text{ W}$

Total power consumption:  $P = 28.6 \text{ W}$

Coefficient of performance (COP):  $\text{COP} = \text{Heat removed} / \text{Power consumed}$   
 $\text{COP} \approx 3.5$

This indicates that the system removes 3.5 watts of heat for every 1 watt of electrical energy consumed.

## VI. FABRICATION AND IMPLEMENTATION

The fabrication of the Battery Thermal Management System involves assembling mechanical, electrical, and control components into a compact structure suitable for electric two-wheeler applications. The battery simulator is mounted on an aluminum base plate, and cooling blocks are attached directly to the heat source using thermal paste to improve heat transfer efficiency.

Flexible PVC pipes are used to connect the coolant reservoir, water pumps, cooling blocks, and radiator, forming a closed-loop liquid circulation system. The ESP32 microcontroller is mounted on a control panel along with relay modules and power supply connections. All wiring is insulated properly to prevent short circuits and ensure safe operation.

The complete system is enclosed in a protective casing to prevent coolant leakage and mechanical damage. Proper ventilation is provided to allow heat dissipation from the radiator fan.

### VII. COST ESTIMATION OF BTMS

Part Name	Quantity	Material	Cost (INR)
ESP32 Microcontroller	1	PCB with Xtensa LX6 chip	₹650
DS18B20 Temperature Sensor	4	Stainless steel probe, TO-92 package	₹800
3-Channel Relay Module	1	PCB with electromagnetic relays	₹350
R385 DC Water Pump	2	ABS plastic housing, brushed DC motor	₹1200
Aluminum Cooling Block	2	Aluminum alloy machined block	₹4500
Spiral Aluminum Tube Radiator	1	Aluminum tubing, spiral coiled	₹2800
120mm x 120mm DC Fan	1	ABS plastic frame, brushless DC motor	₹650
12V 2A DC Power Adapter	1	SMPS, plastic housing	₹550
DC-DC Step-Down Converter	1	PCB with LM2596 chip	₹220
Heatsink with Fan Assembly	2	Aluminum fin heat sink, small DC fan	₹1200
Coolant Reservoir Tank	1	Transparent plastic, 1.5 liter	₹100
Miscellaneous Hardware	-	Various	₹200
<b>Total</b>			<b>₹13,220</b>

### VIII. TESTING PROCEDURE

The system was tested under controlled laboratory conditions using an electrical heater to simulate battery heat generation. Temperature readings were recorded at different locations using digital sensors. The testing procedure included the following steps:

1. Switch on the system power supply.
2. Activate the battery simulator (heater).
3. Monitor temperature rise using sensors.
4. Observe automatic activation of cooling components.
5. Record temperature reduction over time.
6. Repeat test for multiple heat loads.

The system was tested for continuous operation to evaluate reliability and thermal stability.

### IX. PERFORMANCE ANALYSIS

The performance of the proposed BTMS was evaluated based on temperature control efficiency, response time, and power consumption. The results indicated that the system responded quickly to temperature changes and maintained stable thermal conditions.

#### Key observations:

- Maximum temperature reduced by approximately 8–12°C
- Cooling response time was less than 60 seconds

- System operated continuously without overheating
- Power consumption remained within safe limits

These results confirm that the automated liquid cooling system provides reliable thermal management for electric vehicle battery systems.

### X. RESULTS AND DISCUSSION

Experimental testing of the system demonstrated effective temperature control under simulated thermal conditions. When the battery temperature exceeded the threshold values, the cooling components were activated automatically, resulting in a gradual reduction in temperature.

The liquid cooling system maintained the battery temperature below 40°C under continuous heat load conditions. The staged control logic minimized energy consumption by operating components only when necessary. The use of aluminum cooling blocks ensured efficient heat transfer due to their high thermal conductivity.

The system also provided reliable real-time temperature monitoring through the web-based dashboard, enabling users to observe thermal behavior and system performance.

Overall, the proposed BTMS achieved stable operation, efficient heat dissipation, and improved thermal safety.

### XI. SAFETY CONSIDERATIONS

Safety is a critical factor in battery thermal management systems. The following safety measures are implemented in the proposed system:

- Use of insulated electrical wiring
- Leak-proof coolant connections
- Automatic temperature monitoring
- Overheating protection mechanism
- Proper ventilation and heat dissipation
- Secure mounting of components

These safety measures reduce the risk of system failure and ensure reliable operation.

### XII. FUTURE SCOPE

Future development of the Battery Thermal Management System may include:

- Integration of Artificial Intelligence (AI) for predictive cooling
- Use of Phase Change Materials (PCM)
- Solar-powered cooling systems
- Wireless monitoring using IoT technology
- Compact lightweight design for commercial vehicles

- Integration with Battery Management System (BMS)

These advancements can significantly enhance system efficiency and reliability in next-generation electric vehicles.

### XIII. ADVANTAGES OF SYSTEM

- Improved battery life and performance
- Enhanced safety and prevention of thermal runaway
- Energy-efficient operation
- Low-cost and scalable design
- Real-time temperature monitoring
- Suitable for electric two-wheeler applications.

### XIV. LIMITATIONS OF THE SYSTEM

Despite its advantages, the proposed system has certain limitations:

- Requires periodic maintenance of coolant
- Slightly higher cost than air cooling systems
- Dependence on electrical power supply
- Limited portability due to liquid components

Future improvements can address these limitations through advanced design optimization and integration of smart control systems.

### XV. CONCLUSION

This research paper presented the design and development of an automated liquid-based Battery Thermal Management System for electric two-wheelers. The system successfully demonstrated efficient heat removal using a closed-loop liquid cooling mechanism combined with temperature-based control logic. Experimental results confirmed that the system, maintained battery temperature within a safe operating range while consuming relatively low power.

The proposed BTMS offers a practical and cost effective solution for improving battery reliability and safety in electric vehicles, particularly in compact two-wheeler applications. Future work may involve integrating advanced control algorithms such as PID or artificial intelligence-based thermal prediction to further enhance system performance.

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