Design and development of an air-cooled cooling system of EV Battery

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Abstract- This report provides a comprehensive analysis of the design, development, and performance evaluation of an air-cooled cooling system for an electric vehicle battery. The system employs a novel heat sink design incorporating micro-channel technology to enhance heat transfer efficiency. Computational fluid dynamics (CFD) simulations were conducted to optimize airflow distribution and identify potential thermal hotspots. Experimental validation using a prototype battery pack under various operating conditions demonstrated the system's ability to maintain battery temperature within a narrow operating range, ensuring optimal performance and safety. The findings of this research contribute to the advancement of EV thermal management technology and support the development of high-performance, long-lasting electric vehicles. The performance and cost-effectiveness of various heat sink configurations, fan technologies, and airflow management strategies were evaluated. The results of this analysis highlight the advantages and limitations of each design approach. Additionally, future research directions are explored, including the integration of phase change materials for enhanced thermal management and the development of adaptive cooling systems that can respond to dynamic driving conditions.

Key Words: Electric Vehicles, Battery Thermal Management, Air Cooling, CFD, Lithium-Ion, Thermal Simulation, Prototyping.

1. INTRODUCTION

The rapid growth of electric vehicles (EVs) has necessitated the development of efficient and reliable thermal management systems for their batteries. Battery temperature plays a crucial role in determining the vehicle's range, performance, and safety. Excessive heat can lead to battery degradation, reduced capacity, and even thermal runaway, while insufficient cooling can compromise battery performance and longevity.

The design and development of an air-cooled cooling system specifically tailored for an EV battery. The system aims to effectively dissipate heat generated during battery operation, ensuring optimal performance and prolonging battery life. The following sections will delve into the design considerations, system components, thermal analysis, and experimental validation of the proposed cooling system. However, the performance and safety of EVs are heavily reliant on the efficiency of their battery systems, particularly regarding thermal management. As battery technologies advance, managing the heat generated during operation becomes increasingly crucial to ensuring optimal performance, longevity, and safety.

2. AIM

The aim of this project is to design and develop an efficient, lightweight, and cost-effective air-cooled thermal management system for electric vehicle (EV) battery packs. As EVs become increasingly popular, maintaining the battery within its optimal operating temperature range (typically 20°C–40°C) is critical for ensuring performance, safety, and extended battery life. Unlike liquid cooling systems, which are often complex, expensive, and heavy, air-cooling offers a simpler and maintenance-free alternative suitable for small and medium-sized EVs. The project involves analyzing the thermal characteristics and heat generation of lithium-ion batteries during charging and discharging cycles, followed by the conceptual and CAD-based design of a forced-air cooling setup using fans, ducts, and optimized airflow paths. Computational Fluid Dynamics (CFD) simulations will be carried out to evaluate the effectiveness of the design in maintaining uniform cooling and preventing hotspots. Based on simulation results, a prototype of the cooling system will be fabricated and tested under controlled conditions to validate its performance. The expected outcome is a functional air-cooled battery system that improves thermal regulation, reduces the risk of thermal runaway, enhances battery efficiency, and offers a practical solution for use in real-world EV applications, particularly where weight, cost, and simplicity are important factors.

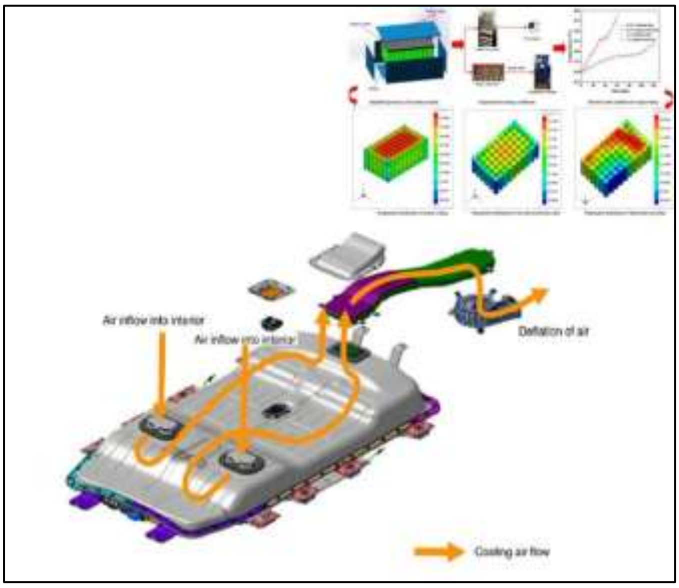


Fig -1: Air colling system

3. Experimental Setup

Component	Description
Battery Module	Simulated with dummy cells + heat sources (resistors or heating pads)
Cooling System	Assembled prototype with axial fans and ducts
Sensors	NTC thermistors or DS18B20 temperature sensors
Control Unit	Arduino-based monitoring and fan control system
Data Logging	Serial monitor / Excel / IoT platform for data recording
Power Supply	12V DC supply for fans and heating elements
Environment	Room temperature (28–35°C), no additional ventilation

4. Fabrication Process

The fabrication of the air-cooled battery thermal management system was carried out in sequential phases based on the validated design model. Initially, the battery enclosure and ducting layout were modelled using CAD software, considering airflow dynamics and thermal constraints. Mild steel and lightweight aluminium sheets were selected for the frame and ducts due to their favourable thermal conductivity, structural strength, and ease of machining. The battery housing was fabricated using CNC laser cutting and bending processes to achieve precise dimensions. Ventilation pathways were integrated into the casing to ensure uniform airflow over the battery cells. High-efficiency DC axial fans were mounted at strategic locations based on CFD simulation results to enable forced convection. Heat sinks made of extruded aluminium fins were attached to the battery surface to enhance heat dissipation. The components were assembled using fasteners and thermally conductive insulating materials to ensure electrical safety and thermal contact. Temperature sensors (thermocouples) and airflow sensors were embedded at key points for performance monitoring. The entire setup was then mounted on a vibration-isolated test bench for functional validation and thermal testing under variable load and ambient conditions.

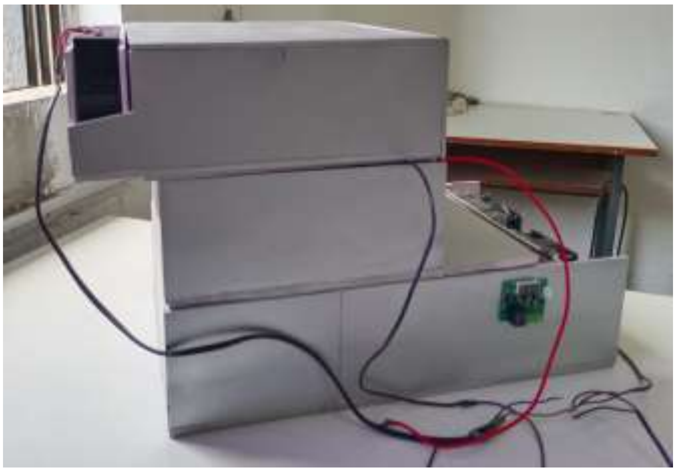


Fig -2: Actual Prototype of the Model

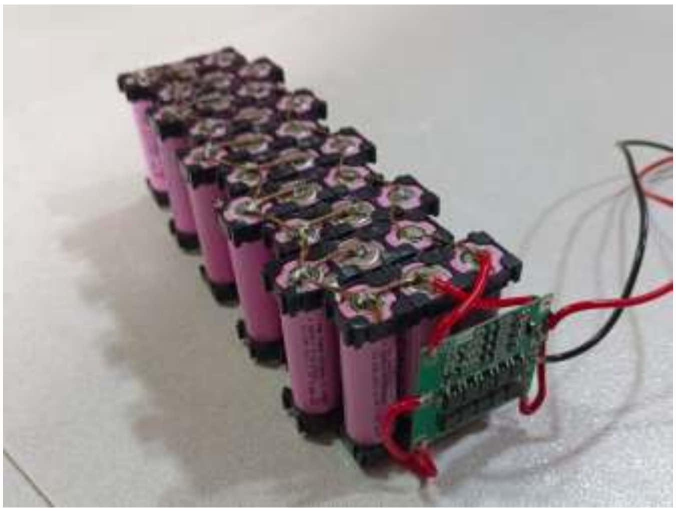


Fig -3: Arrangement of cells

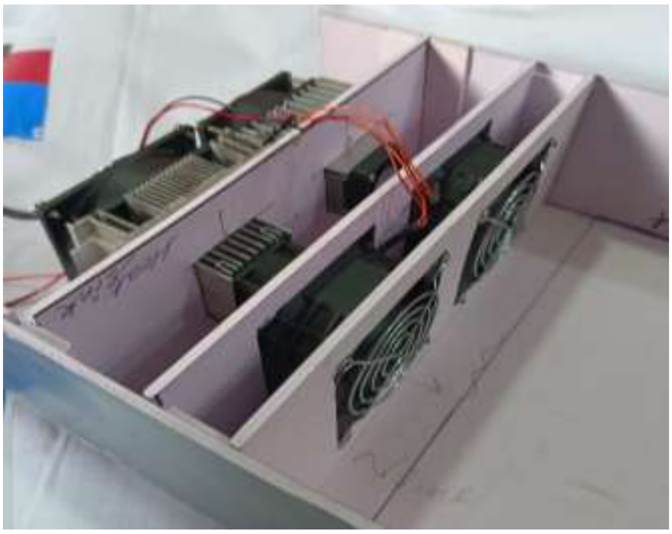


Fig -4: Fans

Fig -1: Setup

5. Experimental Testing and Validation

Tests were conducted in a controlled lab environment, with ambient temperatures maintained between 28°C and 35°C.

Key testing stages included:

5.1 Baseline Measurement (No Cooling) Heating pads simulated a thermal load. Peak temperatures reached ~48°C without active cooling, with significant thermal gradients (>10°C) across the module.

5.2 Active Cooling Test Upon activating the air cooling system, the maximum temperature dropped to ~36°C. Temperature difference between the hottest and coolest cells reduced to <4°C. Airflow effectively maintained thermal uniformity and prevented hotspots.

6. Results and Observations

The experimental testing of the air-based battery cooling system revealed significant improvements in thermal performance when compared to the baseline (no cooling). The data collected from both scenarios—without cooling and with active air cooling—are summarized in the table below:

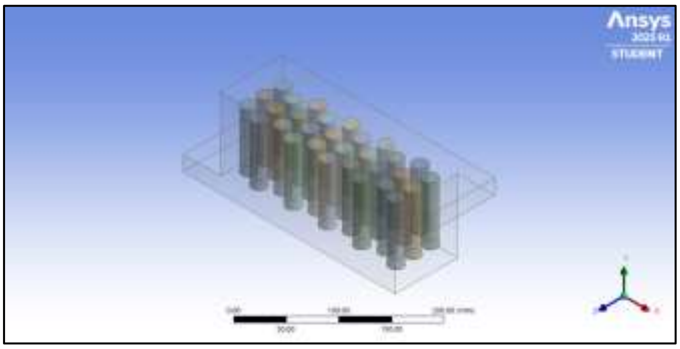
Parameter	Without Cooling	With Air Cooling
Max Battery Temperature	~48°C	~36°C
Time to Reach 40°C	~8 minutes	~15+ minutes
Temperature Uniformity (ΔT)	>10°C	<4°C
Air Outlet Temperature	–	~30°C
Power Consumption (Fans)	–	~8–12W

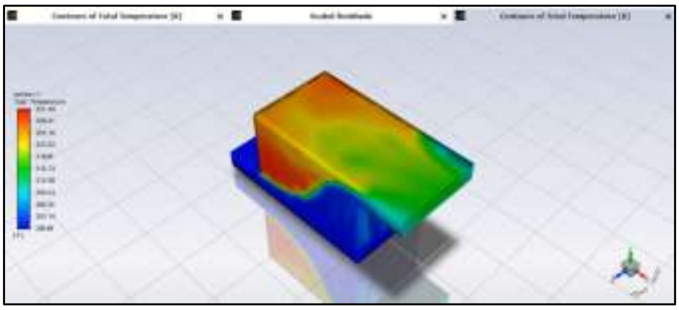
7. Computational Fluid Dynamics (CFD) Analysis

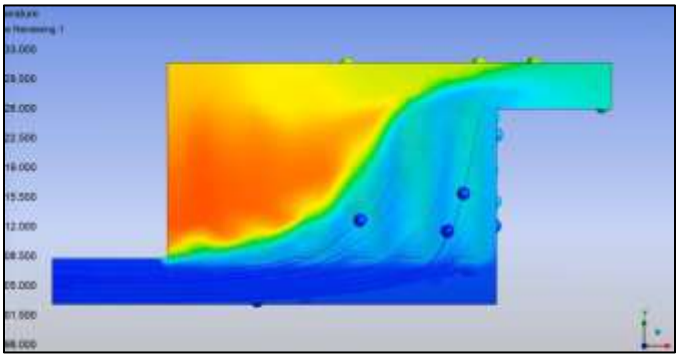
To evaluate the thermal and fluid performance of the system, CFD simulations were conducted using ANSYS Fluent. A CAD model of the battery pack and duct layout was developed in SolidWorks and imported into the simulation environment.

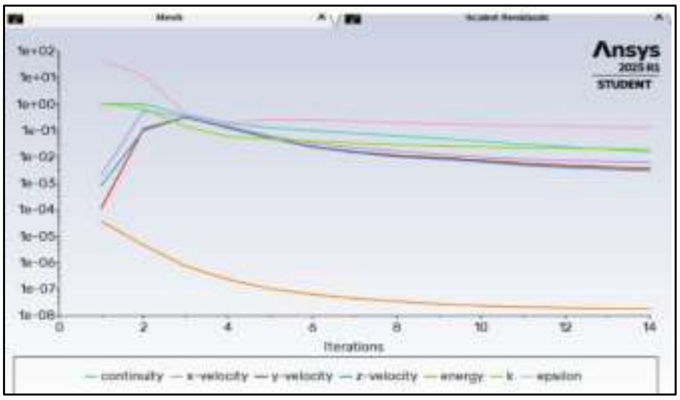
7.1 Objectives of CFD Analysis

Analyze airflow behavior across the battery module
Predict temperature distribution and identify hotspots
Optimize duct geometry and fan positioning for maximum efficiency
Ensure system meets thermal performance criteria under peak loads
Analysis:









Comparison with CFD

Predictions Experimental results closely matched simulation outputs, confirming the reliability of the CFD model. The correlation validated design assumptions and airflow path optimization.

8. Discussion

The air-cooled BTMS successfully demonstrated its ability to manage heat within the desired range while maintaining uniformity. Although not as thermally efficient as liquid systems, the benefits in cost, simplicity, and maintainability make it a practical choice for many EV applications. Design challenges such as airflow distribution and sensor calibration were addressed through iterative testing. The modular design ensures adaptability to various vehicle platforms. Future improvements may include integration with phase change materials or AI-based fan control algorithms.

9. Conclusion

This study presents a viable air-cooled thermal management solution for EV batteries. Through design, simulation, and testing, the system proved effective in reducing temperature, enhancing thermal uniformity, and maintaining safe operation. As EV adoption grows, such systems will be key to supporting performance and safety standards in an environmentally and economically sustainable manner.

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