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Review Paper on Design and Development of an Air-Cooled Cooling System in EV Battery

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Abstract - The performance, safety, and lifespan of electric vehicle (EV) batteries are highly dependent on effective thermal management. Excessive heat generation during charging and discharging cycles can lead to reduced efficiency, accelerated degradation, and potential safety hazards. This project focuses on the design and development of an air-cooled thermal management system for EV battery packs. The proposed system utilizes forced air convection to maintain optimal battery operating temperatures within a safe range. A detailed study of heat generation mechanisms in lithium-ion batteries is conducted to determine cooling requirements. Computational Fluid Dynamics (CFD) simulations and thermal modeling are employed to optimize airflow distribution, fin geometry, and fan placement for maximum cooling efficiency with minimal power consumption. A prototype air-cooled system is developed and tested under varying load conditions to evaluate its performance in terms of temperature uniformity, response time, and energy efficiency. Results demonstrate that the designed air-cooled system effectively regulates battery temperature, ensuring improved performance and extended battery life while maintaining cost effectiveness and structural simplicity compared to liquid cooling systems.

1.INTRODUCTION

Electric vehicles (EVs) have emerged as a key solution to reducing greenhouse gas emissions and dependency on fossil fuels. The heart of any EV is its battery pack, which stores and delivers electrical energy to the drivetrain. However, during charging and discharging processes, significant heat is generated within the battery cells due to internal resistance and electrochemical reactions. If this heat is not effectively dissipated, the battery temperature can rise beyond safe operating limits, leading to performance degradation, reduced lifespan, and even safety hazards such as thermal runaway. To ensure optimal battery performance, a reliable Battery Thermal Management System (BTMS) is essential. The BTMS maintains the battery temperature within the ideal range (typically 20°C to 40°C) and ensures uniform temperature distribution across all cells. Various cooling techniques—such as liquid cooling, phase-change materials, and air cooling—are employed in EVs. Among these, air cooling offers advantages like simplicity, low cost, lightweight design, and ease of maintenance, making it suitable for low to medium power EVs. This project focuses on the design and development of an air-cooled system for EV battery packs. The study involves analyzing heat generation within the battery, designing an optimized airflow path, and selecting appropriate components such as fans and fins to achieve efficient heat dissipation. Computational modeling and experimental validation are performed to assess the system's effectiveness in maintaining thermal stability under various operating conditions.

Methodology

1.Thermal Load Calculation

Estimate the total heat produced under different operating conditions (fast charging, high discharge rates, ambient temperature variations).

2.Cooling Requirement Definition

Set target operating temperature range (typically 20–40 °C) to ensure safety, efficiency, and battery longevity.

3.Airflow Path Design

Create ducting or channels around battery modules to guide airflow uniformly across cells.

4.Forced Convection Implementation

Use fans or blowers to actively push air, enhancing heat transfer compared to natural convection.

5.Humidity & Contaminant Control

Integrate filters or dehumidifiers to prevent moisture condensation and dust accumulation inside the battery pack.

6.Temperature Sensors & Monitoring

Place sensors at critical points to continuously track cell temperatures and detect hotspots.

7.Control Algorithm Integration

Employ smart controllers to adjust fan speed and airflow dynamically based on real-time thermal data.

8.Energy Efficiency Optimization

Balance cooling effectiveness with minimal power consumption to avoid reducing EV driving range.

1. **Basic Principle**

Air cooling relies on **forced convection**: moving air absorbs heat from battery cells and carries it away.

Fans or blowers push ambient or conditioned air through ducts and channels around the battery pack.

2. Heat Generation

During charging/discharging, battery cells generate heat due to internal resistance.

Fast charging can produce thermal loads up to ~2.5 kW.

3.Air Distribution

Air is directed over cells using **ducts, fins, or channels**.

Cooling fins increase surface area for better heat transfer.

4.Heat Dissipation

The moving air absorbs heat and exits the pack, maintaining cell temperature within the safe operating range.

5.Control System

Smart blowers adjust airflow based on temperature sensors.

Some designs use **multi-path ducting** or **hybrid heat pipes** to reduce temperature gradients.

Advantages

Simple & lightweight compared to liquid cooling.

Low cost and easy maintenance.

No risk of coolant leakage.

Limitations

Less effective for **high-energy density batteries**.

Struggles with **uniform cooling**—temperature differences of >5°C can occur between cells.

Performance depends heavily on ambient air temperature and humidity.

Table -1: Sample Table format

THERMAL CALCULATIONS

Calculation Type	Formula	Parameters	Example Values	Result
1. Heat Gencration	$Q_{gen} = I^2 \cdot R_{ru} \cdot t$	Current I Besistance R_{ru}	1 = 300 A R_{h} = 0.01 Q	2400 J
2. Air Cooling	$Q_{air} = m \cdot C_p \cdot \Delta T$	Mass flow rate y Specific heat C_a Temp rise ΔT	m = 0.05 kg/s C_p = 1005 /kg·K ΔT = 10 K	502.5 W
3. Convective Cooling	$Q_{conv} = h \cdot A \cdot \Delta T$	Heat transfer coefficient h Are's A Temp diff ΔT	h = 30 W/m²K A = 0.5 m² –	225 W
4. Energy Balance	$Q_{gen} \le Q_{air}$ or $Q_{gen} \le Q_{conv}$	Compare heat generated vs. neat removed		Must be satisffied for said operation

Fig -1: Figure

Chart

COSTING

Cost Component	Unit	Price	Qty	Sub-Total
Battery Pack	Units	₹ 300	10	₹ 3000
Fan	Units	₹ 200	15	₹ 3000
Ducting	Feet	₹ 40	100	₹ 4000
Labor	Hours	₹ 200	10	₹ 2000
TOTAL COST				₹13000

3. CONCLUSIONS

- Air cooling systems are a simple, low-cost, and lightweight solution for managing battery temperatures in electric vehicles.
- They are most effective in small battery packs, hybrids, or budget EVs where heat generation is moderate.
- However, because air has low thermal conductivity, these systems struggle with fast charging, high-performance driving, and hot climates, leading to risks of uneven cooling and reduced battery lifespan.
- Modern EVs increasingly rely on liquid or refrigerant cooling for better efficiency, uniformity, and durability, while air cooling remains relevant in entry-level EVs and hybrids where affordability and simplicity matter more than peak performance.

FUTURE SCOPE

Air cooling remains one of the simplest and most cost-effective thermal management methods for electric vehicle (EV) batteries. While liquid cooling and advanced phase-change systems are gaining traction, air cooling still has a promising future in specific contexts.

Low Cost & Simplicity: Air cooling systems are cheaper to design, manufacture, and maintain compared to liquid cooling. This makes them attractive for budget EVs and two/three-wheelers.

1.Lightweight Design: No need for pumps, pipes, or coolant fluids, reducing vehicle weight and improving efficiency.

2.Safety: Eliminates risks of coolant leakage or electrical short circuits.

3.Scalability for Small Packs: Ideal for compact EVs, hybrids, and low-power applications where heat generation is moderate.

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