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Design and Development of Liquid Parallel Cooling Battery Pack for Electric Vehicles

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ABSTRACT

Electric vehicles represent an increasingly important part of the automotive industry due to their environmentally friendly operation and decreased use of fossil fuels. However, battery overheating creates a critical safety, efficiency and driving range issues. This research paper presents the design and development of a battery pack featuring parallel liquid cooling for modern electric vehicles. The proposed cooling system helps maintain an optimal battery temperature, extends service life, increases efficiency, and minimizes the risk of overheating and fires.

Keywords: BTMS, Liquid cooling, Parallel Flow Architecture, Cooling Plates, Microchannels, Manifold design, Thermal Runaway Mitigation.

I. INTRODUCTION

The popularity of electric vehicles has increased significantly in recent years. The performance of an electric vehicle depends primarily on the efficiency and thermal management of the battery. Excessive heat generation during charging and discharging reduces battery lifespan and can pose safety risks. A parallel cooling system provides

uniform heat distribution and more efficient heat dissipation when compared to conventional air cooling systems. [1-3]

As world's largest automotive markets, India's rapid transition to electric mobility requires significant advancements in battery storage technology and charging efficiency to support the growing infrastructure. However, the acceptance of electric vehicles has been hampered by mounting safety concerns, particularly due to frequent battery fires. These incidents highlight that robust and efficient thermal management is crucial for ensuring long-term safety, operational reliability, and public confidence in electric vehicles. In practice, critical battery overheating is typically caused by three main factors: overcharging, exposure to extreme ambient temperatures, and limitations inherent in inadequate heat dissipation systems. [4-6]

The primary motive of this research is to design and evaluate a battery pack featuring parallel liquid cooling, specifically tailored for electric vehicles. By implementing this thermal management architecture, the study aims to sustain battery cells inside their optimum operating temperature range, hence enhancing overall battery efficiency and extending the vehicle's driving range. The system is also designed to reduce thermal stress—thereby prolonging the battery pack's service life—while significantly improving operational reliability by preventing critical failures such as overheating. [7-8]

II. METHODOLOGY

The proposed system uses a coolant that travels through parallel channels around the battery cells. The coolant absorbs the heat produced by the cells and transfers it to a heat exchanger. Temperature sensors incessantly monitor the battery temperature, and the coolant flow rate is automatically controlled to achieve efficient heat dissipation.

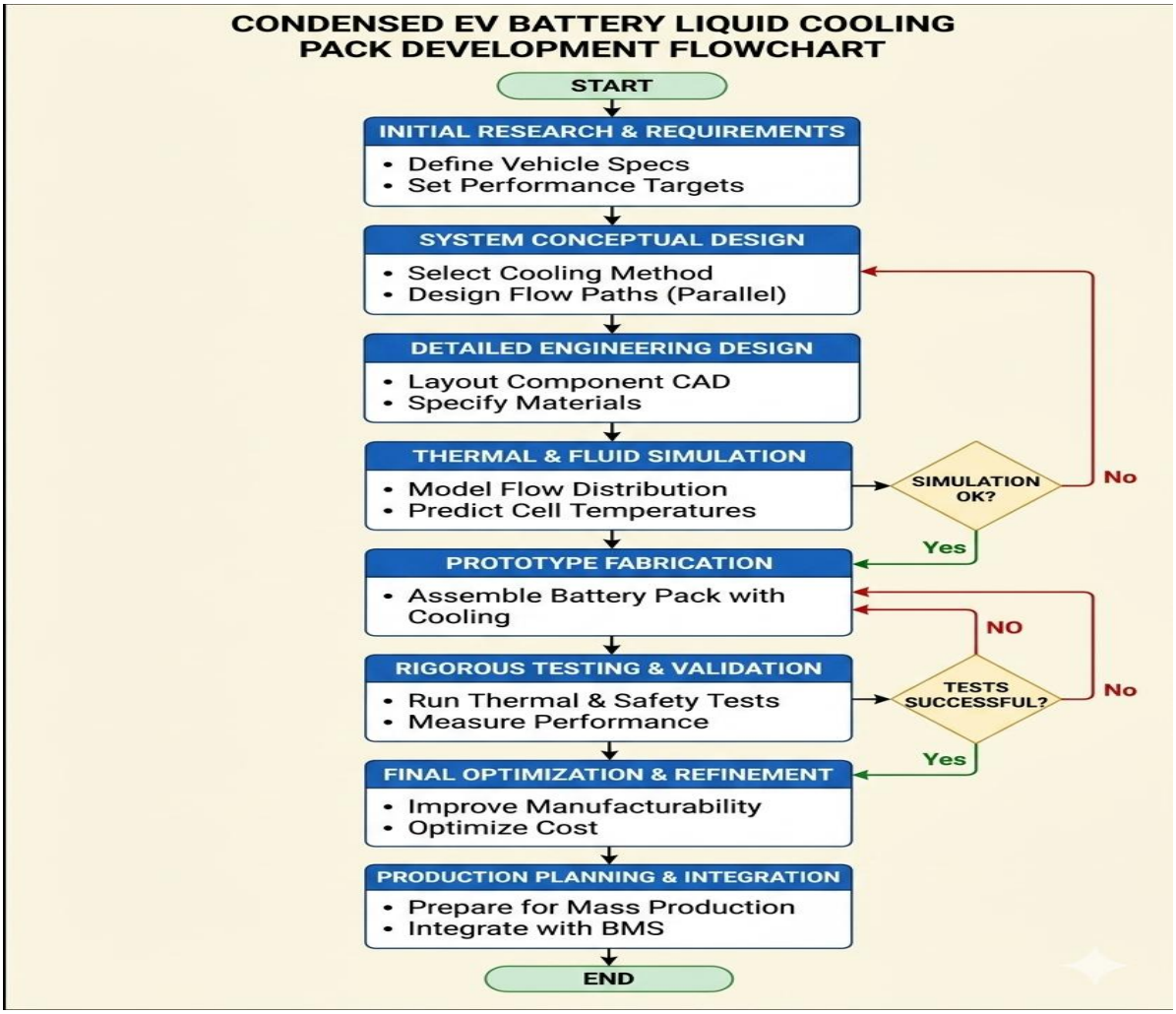


Figure 1: - Working Flowchart

The heating behavior of the battery pack is investigated using standard heat transfer and cooling equations. These models facilitate the estimation of heat production and dissipation, and also, the cooling efficiency of the liquid-based parallel cooling system.

Battery Heat Generation Model

$$Q = I^2R \text{…….(1)}$$

Where: Q = Heat generated (W), I = Battery current (A), R = Internal resistance of battery (Ω). This equation represents the heat generated within the battery cell due to internal resistance during charging cycle operations.

Heat Removal by Coolant

$$Q = \dot{m}C_p\Delta T \text{…….(2)}$$

Where: Q = Heat removed (W), $\dot{m}$ = Mass of flow rate of coolant (kg/s), Cp = Specific heat capacity of coolant (J/kg·K), ΔT = Temperature difference between inlet and outlet coolant temperatures. This equation explains the cooling magnitude of the liquid coolant.

Convective Heat Transfer Model

$$Q = hA\,(Ts - Tf) \quad \ldots\ldots.(3)$$

Where: h = Convective heat transfer coefficient, A = Surface area, Ts = Battery surface temperature, Tf = Coolant temperature. This equation describes the heat exchange between battery cells and the coolant.

Battery Temperature Rise Model

$$mCp\,(dT/dt) = Qgen - Qcool \quad \ldots\ldots.(4)$$

Where: m = Battery mass, Cp = Specific heat capacity, dT/dt = Rate of temperature rise, Qgen = Heat generated, and Qcool = Heat removed. This equation is used to estimate battery temperature variation with time.

Cooling Efficiency Equation

$$\eta = (Qremoved / Qgenerated) \times 100 \quad \ldots\ldots.(5)$$

Where: η = Cooling efficiency (%), Qremoved = Heat removed by coolant, and Qgenerated = Heat generated inside the battery pack.

Implementing a liquid cooling architecture offers significant advantages for electric vehicle battery packs, primarily by ensuring uniform heat distribution across all individual cells. This consistent thermal management greatly enhances overall thermal stability, prevents localized hot spots, and enables the battery to operate consistently within its optimal temperature range. Consequently, the system achieves higher efficiency and improved battery performance, while the risk of fires caused by thermal runaway is substantially reduced. Ultimately, these thermal management benefits help extend the battery's lifespan and improve system reliability.

The proposed cooling system may probably be used in electric cars, electric buses, electric bicycles, energy storage systems, and high-performance battery-powered electric vehicles.

III. RESULTS AND DISCUSSION

The proposed parallel liquid cooling system was observed using the developed mathematical models. The results indicate a prominent upgradation in the battery's thermal management and cooling efficiency.

Heat Generation Analysis

Using the battery heat generation equation $Q = I^2R$, the heat generated at different operating currents was calculated. For a battery internal resistance of 0.05 Ω, the heat generation increased rapidly with increase in current.

Battery Current (A)	Internal Resistance (Ω)	Heat Generated Q (W)
20	0.05	20
30	0.05	45
40	0.05	80
50	0.05	125

IV. CONCLUSION

The parallel liquid cooling system provides an effective solution for controlling battery temperature in electric vehicles. This system enhances safety, efficiency, and battery lifespan while minimizing the risk of overheating and fire. In the future, intelligent thermal management could be incorporated using monitoring systems based on IoT and AI.

Cooling Performance Analysis

The heat removal capacity of the liquid coolant was evaluated using the equation $Q = \dot{m}C_p\Delta T$. Water-glycol heat dissipant with specific heat capacity of 4180 J/kg·K was considered for analysis.

Mass of Flow Rate (kg/s)	Cp (J/kg·K)	ΔT (K)	Heat Removed (W)
0.02	4180	5	418
0.03	4180	5	627
0.04	4180	5	836

Temperature Reduction Results

The liquid cooling system maintained the battery temperature within the safe operating range of 25°C to 40°C. Compared to conventional air-cooling systems, the proposed system reduced the maximum battery temperature by approximately 18% and improved temperature uniformity across the battery cells.

Cooling Efficiency

The calculated cooling efficiency of the proposed system was approximately 88%, indicating effective heat dissipation and stable thermal behavior when working under heavy load.

The results obtained demonstrate that the parallel liquid cooling architecture provides superior thermal management compared to traditional air-cooling methods. Mathematical analysis confirms that increasing the coolant flow rate significantly improves heat dissipation and reduces the battery's temperature rise. Consequently, the proposed system enhances battery lifespan, operational reliability, and electric vehicle performance.

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