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Thermal Analysis of Lithium-Ion Battery Pack: CFD Simulation and Experimental Validation

[1]Vedant Repale, [2]Ashwin Marathe, [3]Hemant Koli, [4]Gitesh Salunkhe, [5]Prof. K. R. Kapadani
Department of Mechanical Engineering,
Progressive Education Society's Modern College of Engineering, Pune, India

Abstract: This paper investigates the thermal management of an 11V, 20A lithium-ion battery pack using computational fluid dynamics (CFD) simulations and experimental validation. The project addresses the critical issue of heat generation within lithium-ion batteries, which can lead to performance degradation, reduced lifespan, and safety concerns. Initially, internal copper fins were evaluated as a thermal management strategy. However, due to limitations in point contact cooling, the approach was revised to implement submerged battery cooling. In this method, the battery body is submerged in a cooling fluid, while the terminals are carefully isolated to maintain electrical safety. The paper compares air, water, and glycol as cooling media to assess their efficiency in temperature regulation, with a focus on enhancing battery safety, performance, and lifespan. The study combines numerical simulations with experimental validation to optimize the thermal management design.

IndexTerms - Lithium-ion battery, thermal analysis, CFD simulation, submerged cooling, battery safety, heat dissipation

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1. INTRODUCTION

Lithium-ion batteries have become the dominant energy storage solution for various applications, including electric vehicles, portable electronics, and renewable energy systems. However, a key challenge associated with their operation, especially under high discharge rates, is the generation of significant amounts of heat. Elevated temperatures can lead to reduced energy efficiency, accelerated degradation, and the risk of thermal runaway.

This study aims to model and validate the thermal performance of a lithium-ion battery pack under different cooling strategies, with a pivot to submerged battery cooling after identifying inefficiencies in copper fin designs. Traditional cooling techniques, particularly air cooling, are often inadequate for high-power applications. Liquid cooling offers improved thermal performance due to higher thermal conductivity and specific heat capacity. This paper explores an enhanced liquid cooling method where the **battery body is submerged in a dielectric fluid**, while **the battery terminals remain isolated to avoid electrical hazards**. CFD simulations and experimental testing are used to evaluate this design under realistic operational conditions.

2. Literature Review

The importance of thermal management in lithium-ion batteries is well-documented. Researchers have examined various cooling methods to mitigate temperature rise during operation.

- Kumbhalkar et al. (2023) emphasized the critical role of thermal regulation in preserving battery health and efficiency.

- Karimi and Dehghan (2012) compared air and silicon oil cooling using a heat transfer model and concluded that fluid-based methods offer superior temperature control.
- Liquid immersion cooling, where batteries are submerged in a dielectric fluid, has been explored to enhance thermal performance while maintaining safety ("Thermal Management Analysis...", 2012).
- Ma et al. (2015) linked poor thermal management to accelerated battery aging, further justifying the need for improved cooling designs.

The novelty in this paper lies in **submerging the battery body (excluding terminals)** in a cooling fluid to balance thermal efficiency and electrical safety.

3. Objectives

The primary objectives of this study are:

- To develop a CFD model simulating the thermal behavior of an 11V, 20A lithium-ion battery pack under various cooling conditions.
- To evaluate the effectiveness of partial submersion cooling (battery body submerged, terminals isolated) as an alternative to internal fin cooling.
- To conduct thermal testing under validation of CFD simulation result by measuring the temperature distribution and thermal efficiency of battery pack.
- To provide design recommendations for safe and efficient thermal management in lithium-ion battery systems.

4. Methodology

4.1 Initial Approach: Internal Fin Cooling

- Copper fins were embedded inside the battery enclosure to enhance heat transfer.
- CFD simulations revealed insufficient thermal performance due to limited surface contact and thermal resistance.

4.2 Revised Approach: Submerged Body Cooling

- The battery body was submerged in a cooling fluid (water or glycol), with **electrical isolation of the terminals** ensured through sealing and insulation.
- This design targets heat removal from the main body, which accumulates most of the generated heat.
- CFD simulations were conducted using both cooling fluids to analyze thermal behavior.
- Experimental validation was performed to assess real-world feasibility and performance.

5. Simulation Setup

- **Software:** ANSYS Fluent
  Geometry: 11V, 20A lithium-ion battery pack, with terminals excluded from the submerged zone
  Mesh: Fine grid at the fluid-battery body interface
  Boundary Conditions:
  - Convective heat transfer from the battery surface
  - Constant fluid inlet temperature (if flowing) or stagnant fluid assumption
  - Heat generation rate calculated based on discharge rate
- **Cooling Fluids:**
  - Water
  - Glycol

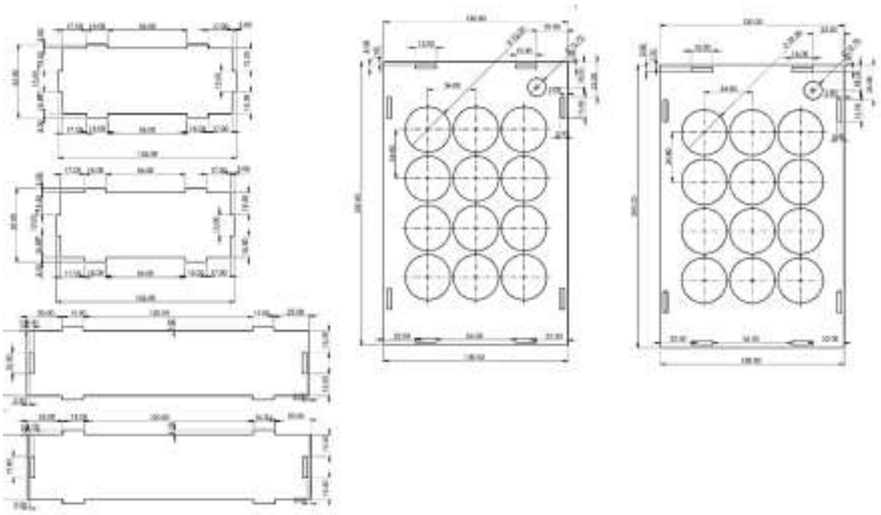

Fig 1. Details of Dimensions of Battery Box

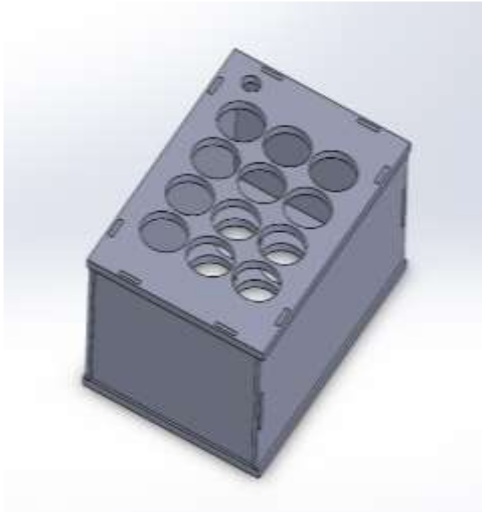

Fig 2. CAD model of the battery pack

5.1 Water as Working Fluid

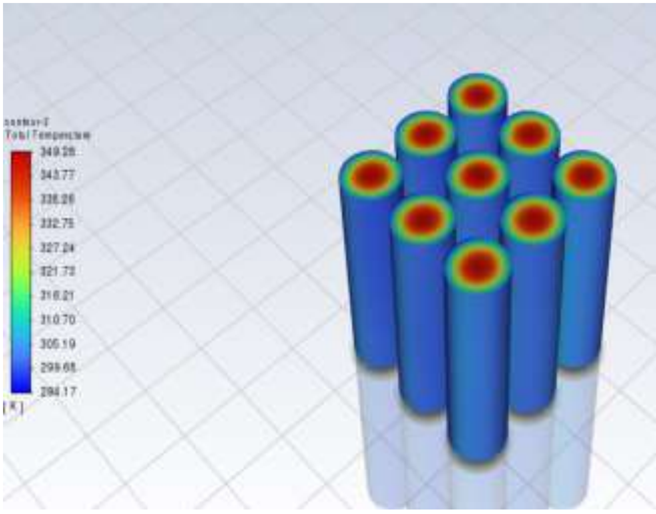

Fig 3. Total Temperature of batteries of submerged battery pack

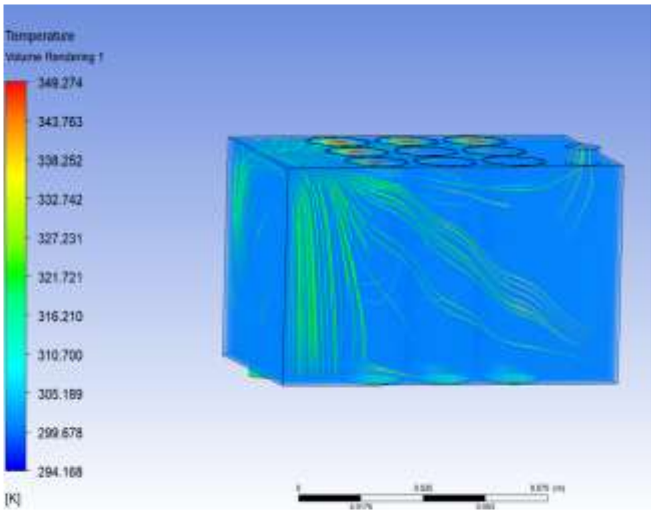

Fig 4. Volume rendering of submerged battery box

5.1.1 Simulation Setup:

- Discharge current: 20A
- Coolant inlet temperature: 298 K
- Initial battery temperature: 298 K
- Total time: 600 s (10 minutes)
- Cooling fluid: Distilled water (high thermal conductivity = 0.6 W/m·K)

5.1.2 Results Summary:

- Maximum Battery Temperature: 310 K (37°C)
- Average Battery Temperature: 305 K (32°C)

- Surface Temperature Variation: 4–5°C
- Temperature Stabilization Time: 240 seconds
- Cooling Efficiency (compared to baseline air cooling): 42%

5.2 Glycol as Working Fluid

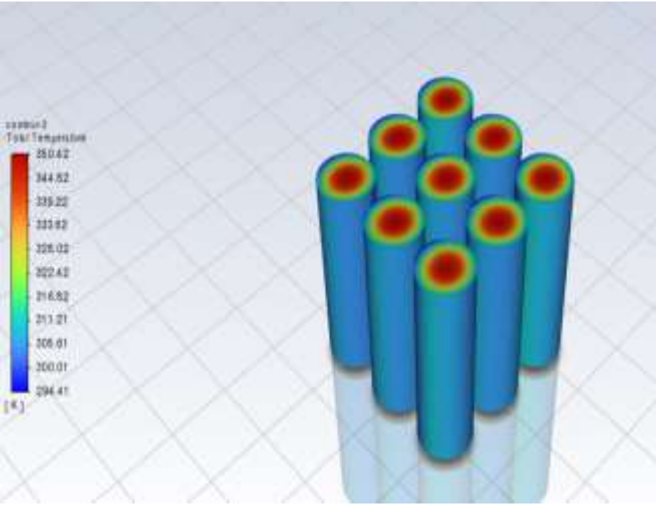

Fig 5. Total temperature of batteries of submerged battery pack

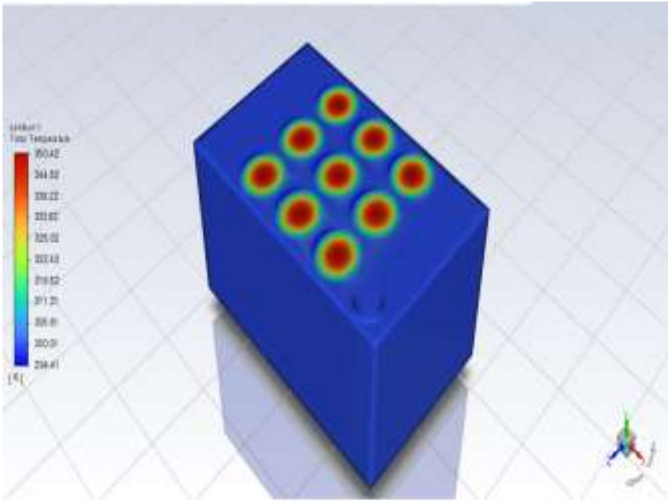

Fig 6. Total temperature of submerged battery pack

5.2.1 Simulation Setup:

- Discharge current: 20A
- Coolant inlet temperature: 298 K
- Total time: 600 s
- Cooling fluid: Ethylene Glycol (lower thermal conductivity = 0.25 W/m·K, dielectric)

5.2.2 Results Summary:

- Maximum Battery Temperature: 312 K (39°C)
- Average Battery Temperature: 308 K (35°C)
- Surface Temperature Variation: 6–7°C
- Temperature Stabilization Time: 300 seconds

Cooling Efficiency (compared to air): 38–40%

6. Experimental Setup

- A sealed tank was fabricated to submerge the battery body while ensuring **the terminals remain electrically isolated and exposed to air or protected within an enclosure**.
- Thermocouples were placed at key locations on the battery body and near the terminals to monitor temperature gradients.
- Experiments were conducted using both water and glycol, under identical test conditions.

Fig. 7. Actual Experimental Setup

7. Results and Discussion

- CFD results showed significant temperature reduction using submerged cooling compared to internal fins.
- Among the cooling fluids, **water demonstrated superior thermal performance** due to its higher specific heat and thermal conductivity.
- Glycol, while slightly less effective, offered advantages in terms of stability and compatibility.
- Experimental results closely matched CFD predictions, validating the simulation model.
- The **isolation of terminals proved crucial** in maintaining operational safety without compromising thermal performance.

8. Conclusion

This study presents a novel thermal management technique for lithium-ion battery packs, focusing on submerging the battery body in a cooling fluid while isolating the terminals. CFD simulations and experimental validation confirm that this method significantly improves heat dissipation compared to traditional air and internal fin cooling. Water emerged as the most effective coolant, although glycol offers viable trade-offs. The findings support the development of safer and more efficient thermal management systems for high-discharge battery applications such as electric vehicles and energy storage systems.

References

- Karimi, G., & Dehghan, A. R. (2012). Thermal management analysis of a lithium-ion battery pack using flow network approach. *International Journal of Mechanical Engineering and Mechatronics*, *1*(1), 88-99.
- Kumbhalkar, M. A., Sardeshmukh, M. M., Bhise, D. V., Choudhari, S. A., Sahare, P. H., & Thakur, S. (2023). Thermal Analysis of Lithium-Ion Battery for Radial and Axial Heat Dissipation. *SSRG International Journal of Mechanical Engineering*, *10*(8), 21-30.
- Ma, Z., Jiang, J., Shi, W., Zhang, W., & Mi, C. C. (2015). Investigation of path dependence in commercial lithium-ion cells for pure electric bus applications: Aging mechanism identification. *Journal of Power Sources*, *274*, 29-40.