Design and Analysis of Cooling Jacket Geometry for Enhanced Thermal Regulation of Li-Ion Cells

Bhushan Karamkar[1], Atharva Potdar[2], Shubham Kawade[3], Sujay Khadse[4], Vikas Pawar[5]
Dhole Patil College of Engineering, Pune

***Abstract*—The global shift toward electric mobility has positioned lithium-ion batteries as a critical component in determining the performance, safety, and reliability of electric vehicles. These batteries exhibit high sensitivity to temperature variations, which significantly influences efficiency, degradation rates, and overall lifespan. To address these thermal issues, Battery Thermal Management Systems have been introduced to maintain battery temperatures within the optimal range of 15°C to 35°C. Among available techniques, liquid cooling has demonstrated superior effectiveness due to enhanced heat transfer capabilities and uniform temperature distribution across battery modules. Advancements in BTMS design are reviewed in this study, with a focus on liquid-cooled systems and findings from recent research and experimental analyses. Various coolant types, channel geometries, and configuration approaches are examined to evaluate thermal performance and system efficiency. The results highlight the importance of effective thermoregulation in promoting battery longevity and ensuring safety while recognizing trade-offs involving complexity, cost, and performance. Optimized liquid cooling systems, particularly those integrating microchannel configurations and phase change-assisted mechanisms, are identified as promising solutions for future BTMS development in EVs.**

***Index Terms*—Lithium-ion battery; Battery Thermal Management System; Liquid-cooled BTMS; Air-cooled BTMS; Serpent Tube; Heat transfer; steady static thermal analysis; Indirect liquid cooling**

I. INTRODUCTION

The transition to sustainable transportation has elevated the role of electric vehicles in reducing environmental impact. At the core of these vehicles lies the lithium-ion battery a costly and complex component that directly affects performance, range, and safety. However, these batteries remain highly susceptible to temperature deviations. Ensuring operation within a controlled temperature range of 15°C to 35°C is essential, as departures from this range contribute to capacity loss, accelerated degradation, and the risk of thermal runaway. To mitigate such thermal challenges, the integration of a Battery Thermal Management System has become a vital element in modern EV architecture. The BTMS is designed to regulate cell temperatures, promote uniform heat distribution, and prevent thermal imbalances during varying operational conditions. Its implementation improves battery life, enhances system efficiency, and ensures safety during vehicle operation. The BTMS is designed to regulate cell temperatures and support the evaluation of diverse cooling strategies including air-based, liquid-based, and PCM-based systems. Each technique presents distinct advantages and limitations. A literature-based review has been conducted to examine industrial practices and technological progress, contributing to the evolving understanding of thermal management in electric mobility. Among the investigated techniques, liquid cooling has received significant attention due to its ability to maintain optimal temperatures and deliver efficient heat dissipation. Unlike air cooling systems, liquid-based methods involve circulation of a coolant typically a water-glycol solution through specialized channels or jackets enclosing battery cells. This method ensures consistent temperature distribution and effective thermal regulation, improving safety and extending battery lifespan. Despite increased design complexity and higher component costs such as pumps and heat exchangers liquid-cooled systems provide advantages that are particularly beneficial for high-performance EVs. This study explores the configuration, functionality, and benefits of liquid-cooled BTMS to assess their practicality and efficiency in modern electric vehicle applications.

II. LITERATURE REVIEW

Recent studies emphasize various thermal management techniques:

- Phase Change Materials (PCMs): Provide passive cooling, high latent heat. Challenges include low thermal conductivity, addressed via fillers and hybrid designs.
- Nanofluids: Enhance thermal conductivity when nanoparticles (e.g., Al2O3, CuO) are added to traditional coolants. CFD simulations show better heat transfer, but concerns include agglomeration and stability.
- Comparative Cooling Strategies: Liquid cooling outperforms air cooling. PCMs provide low-maintenance benefits. Hybrid systems offer combined advantages.
- Bio-based PCMs: Environmentally friendly alternatives to paraffin, showing good latent heat properties. Improved using carbon fillers or nanoparticles.
- Simulations: ANSYS modeling reveals that enhanced PCM materials reduce peak battery temperatures. Simulations suggest optimal PCM geometries and loading.
- Hybrid Systems: Combine air, liquid, PCM, and thermoelectric methods. Provide synergistic thermal regulation but increase system complexity and cost.

III. METHODOLOGY

The thermal analysis of the Battery Thermal Management System (BTMS) was conducted following a structured methodology, comprising the following stages:

DESIGN IN CATIA
↓
MESHING
↓
STEADY STATIC THERMAL SETUP
↓
ANALYSIS
↓
CONCLUSION

IV. STEPS

A. Design and Modeling Two configurations were created in CATIA V5:

- Without gap (closely packed cells)
- With 5 mm gap between cells

Both used serpentine tubes for indirect liquid cooling. Designs were exported in IGES format for simulation.

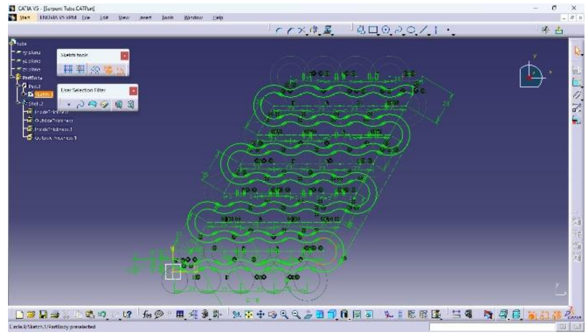

Figure 1: 2D Cooling Jacket (Without gap)

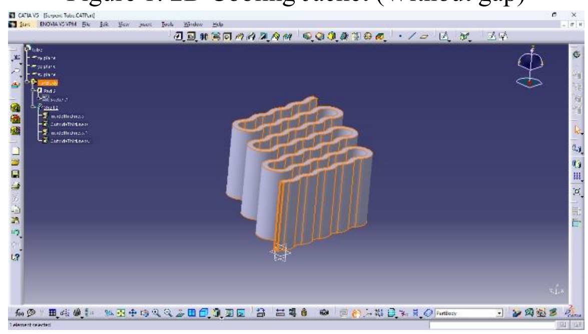

Figure 2: 3D Cooling Jacket (Without gap)

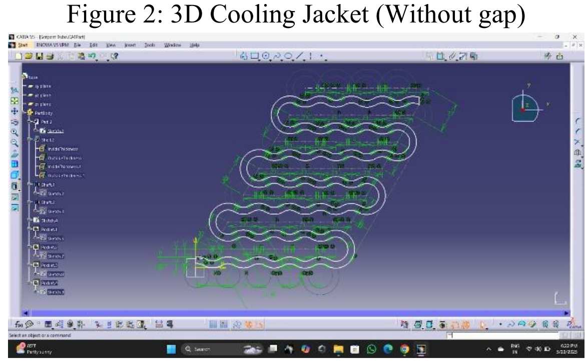

Figure 3: 2D Cooling Jacket (With gap)

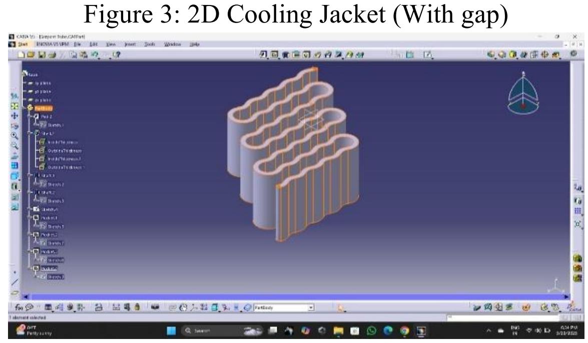

Figure 4: 3D Cooling Jacket (With gap)

B. Meshing Performed in ANSYS Workbench 2024 R1:

- Model 1 (With gap): 943,798 nodes, 499,854 elements
- Model 2 (Without gap): 867,540 nodes, 462,208 elements

Fine mesh with 1 mm element size and adaptive meshing applied.

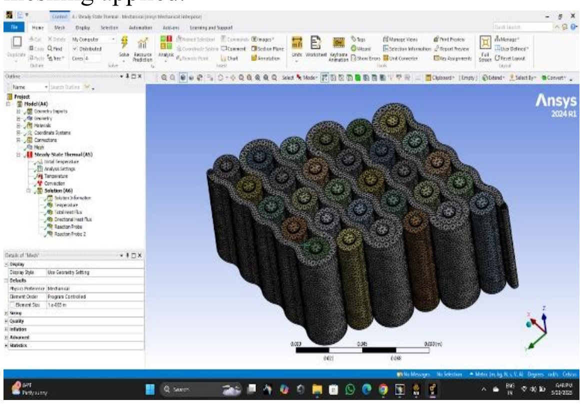

Figure 5: Mesh generated on the cooling jacket model

C. Thermal Setup

- Initial Temperature: 22°C
- Convection Coefficient: 800 W/m²°C
- Cooling Jacket: Aluminium 3003
- Cell Thermal Conductivity: 0.9 W/m°C

Bonded thermal contacts applied to all components.

D. Simulation and Analysis Results from ANSYS simulations:

With Gap:

- Max Temp: 50.32°C
- Min Temp: 23.95°C
- Avg Temp: 45.36°C
- Heat Removed: 4545.7 W

Without Gap:

- Max Temp: 50.51°C
- Min Temp: 24.05°C
- Avg Temp: 47.59°C
- Heat Removed: 3790.7 W

V. CONCLUSION

The spaced-cell configuration demonstrated better thermal performance: lower average and peak temperatures, and higher heat removal. The 5 mm gap improved coolant flow and uniformity. Although it reduces packing density, this configuration provides more reliable thermal control for Li-ion battery applications

VI. PUBLICATIONPRINCIPLES

This research paper, titled “Design and Analysis of Cooling Jacket Geometry for Enhanced Thermal Regulation of Li-Ion Cells,” presents original work carried out by the author(s) as part of their undergraduate engineering project. The contents of the paper have been prepared honestly and responsibly, with all referenced material properly cited.

The paper contributes to the academic and practical understanding of battery thermal management systems by offering a comparative thermal analysis of different cooling configurations. The simulation-based approach using ANSYS software provides verifiable and replicable results, with sufficient technical detail to enable similar experiments or improvements in future work.

The work adheres to the standards of academic integrity and publication ethics. The author(s) confirm that:

1. The paper advances the state of knowledge in the area of battery thermal management in electric vehicles.
2. The content is original, unpublished, and has not been submitted elsewhere.
3. All simulation methods, material properties, and design steps have been described clearly to allow reproducibility.
4. The findings are supported by appropriate data, figures, and analysis.

The author(s) grant IJIRT the right to publish and disseminate this paper and agree to comply with its publication policies.

APPENDIX

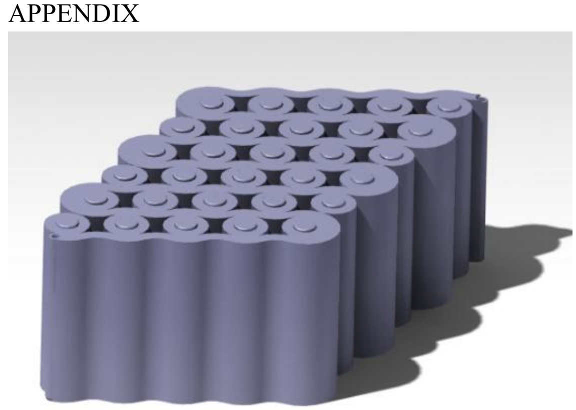

Figure 6: Cell Arrangement with 5 mm Gap

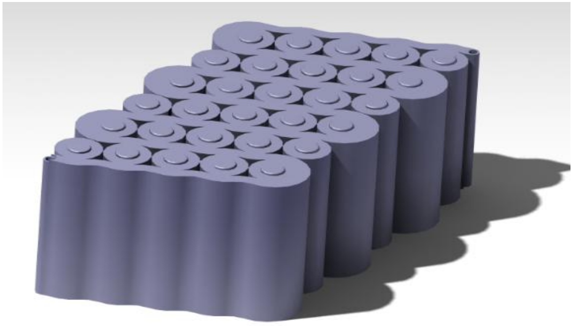

Figure 7: Cell Arrangement Without Gap

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REFERENCES

[1] Fathabadi, H. (2023). Overview of PCM-based BTMS, hyrid systems, and performance evaluations.
[2] Suresh,S. et al. (2022). Nanofluids in BTMS, experimenal validation, and CFD modeling.
[3] Ali, M. et al. (2021). Comparative review of air, liquid, and PCM-based cooling strategies.
[4] Ma, X. et al. (2021). Study on bio-based PCMs for sustainable battery cooling.
[5] Karamkar, A. et al. (2024). Numerical simulation of PCM-integrated BTMS using ANSYS Fluent.
[6] Xu, Y. et al. (2021). Simulation study on PCM-enhanced cooling effectiveness under high loads.
[7] Batra, R. et al. (2021). Review on hybrid BTMS integrating multiple cooling techniques.
[8] Dhumal, A. R. et al. (2023). Review on thermal management of electronic devices.
[9] Rahman, M. A. et al. (2024). Review of innovative heat sink designs and optimization techniques.
[10] Lu, K. et al. (2022). Topological structures for microchannel heat sink applications: A review.