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"DESIGN AND DEVELOPMENT OF AN INDUSTRY-COMPATIBLE ALUMINIUM COOLING JACKET FOR A 25-CELL LITHIUM-ION BATTERY THERMAL MANAGEMENT SYSTEM"

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ABSTRACT

This paper presents the design and development of an industry-compatible aluminium cooling jacket for a 25-cell lithium-ion battery pack intended for electric vehicle battery thermal management systems (BTMS). Efficient thermal management is essential for maintaining battery safety, performance, and service life under high charging and discharging conditions. Unlike many existing cooling solutions that require significant modifications to battery pack architecture, the proposed cooling jacket is designed to integrate directly within the existing 5 mm spacing of standard polymer cell holders, thereby preserving current industrial assembly practices.

The cooling jacket was developed using CATIA V5 with emphasis on manufacturability, compactness, and effective thermal contact with cylindrical 18650 lithium-ion cells. Aluminum 3003 was selected as the cooling jacket material because of its high thermal conductivity, corrosion resistance, low weight, and ease of fabrication. The design incorporates serpentine like coolant channels that maximize heat transfer while maintaining structural integrity and compatibility with existing battery modules.

The proposed configuration provides a practical solution that minimizes manufacturing modifications while improving the thermal interface between coolant and battery cells. The design methodology demonstrates how industrial constraints, material selection, and packaging requirements can be combined to develop a scalable cooling solution suitable for electric vehicle battery packs. This study establishes a strong foundation for subsequent computational and experimental thermal performance evaluations.

KEYWORDS
Battery Thermal Management System (BTMS)
Lithium-Ion Battery
Cooling Jacket
18650 Li-ion Cells
Aluminum 3003
Electric Vehicle
CATIA V5

1.INTRODUCTION

1.1 Proliferation of Electric Mobility

The accelerating worldwide transition toward electric vehicles (EVs) has increased the demand for highly dependable, safe, and efficient energy storage architectures. Owing to their elevated energy densities, extended cycle life, marginal self-discharge behavior, and superior power delivery characteristics, lithium-ion packs represent the premier energy source for contemporary electromobility. Among competing chemistries, Lithium Nickel Manganese Cobalt Oxide (NMC) variants are widely deployed because they strike an optimal equilibrium between power throughput, energy density, and structural longevity.

Nevertheless, the operating temperature profile heavily dictates both performance efficiency and safety, rendering an engineered Battery Thermal Management System (BTMS) a fundamental prerequisite for modern vehicles. Comprehensive literature assessments, such as the review by Karamkar [1], underscore that maintaining core cell temperatures within a strict operational window is critical for ensuring pack safety, reliability, and long-term service viability.

1.2 Thermal Management Imperatives

During aggressive charging protocols and heavy power-draw cycles, lithium-ion cells generate substantial internal thermal energy driven by electrochemical reactions and ohmic resistance. If this heat flux is not promptly dissipated, extreme temperature escalation can accelerate capacity fading, induce non-uniform degradation across cells, degrade power envelope capabilities, and ultimately catalyze catastrophic thermal runaway.

Consequently, suppressing the maximum cell temperature while minimizing the spatial thermal gradient across the module remains a primary objective. Investigations within the academic domain highlight that robust BTMS architectures substantially extend cell lifespan, optimize rapid-charging windows, and secure operational safety under demanding dynamic driving conditions.

1.3 Existing Cooling Technologies

- **Air Cooling**

Thermal management via forced or natural air distribution represents the most straightforward and cost-effective methodology owing to its minimal weight penalty and complex architecture. Nevertheless, the inherently constrained heat capacity and low thermal conductivity of air severely restrict its efficacy in high-power battery packs, frequently resulting in inadequate spatial temperature uniformity and the formation of localized hot spots. These operational bottlenecks have been comprehensively documented in previous Study.

- **Liquid Cooling**

Indirect liquid circulation has emerged as the standard configuration for modern electric vehicle applications, because the thermal conductivities and volumetric heat capacities of liquid media far exceed those of air. The implementation of indirect liquid circuits, such as integrated cold plates, thermal cooling jackets, or convoluted serpentine channels, enables superior temperature uniformity while preserving vital electrical isolation between the working fluid and active cell surfaces.

As detailed by Liu et al. [2] and Zhou et al. [3], modern indirect configurations have high reliability. Furthermore, Trivedi [4] and Fayaz & Afzal [5] demonstrated that meticulously optimized liquid flow geometries can drastically suppress peak cell temperatures while maintaining pump pressure penalties within acceptable thresholds.

- **Phase Change Material (PCM) Cooling**

Passive thermal regulation can be achieved using phase-change materials, which absorb substantial latent heat during solid-liquid phase transitions without requiring external parasitic power. However, the poor intrinsic thermal conductivity of pristine PCMs hinders continuous thermal dissipation during prolonged deployment, rendering unassisted PCM systems ill-suited for sustained high-load driving cycles unless they are augmented with highly conductive structural scaffolds or auxiliary liquid cooling loops.

- **Hybrid Cooling Systems**

Multimode or hybrid thermal management strategies integrate multiple cooling techniques, such as combining liquid channels with phase-change matrices or porous metal foams, to simultaneously optimize transient peak heat dissipation and spatial temperature uniformity.

Recent academic literature reviews, including those by Maiorino [6], Hwang et al. [7], and Pessoa [8], indicate that these synergistic configurations successfully balance operational reliability and thermal efficacy, although they typically introduce elevated fabrication complexity and increased total system costs.

1.4 Identified Research Gap

Although a vast array of BTMS configurations have been detailed in the published literature, a significant portion of liquid-cooled systems require highly customized chill plates, intricate internal fluid routing, or fundamentally altered module architectures that disrupt conventional pack integration. These structural modifications inherently increase production costs, complicate assembly sequences, lengthen manufacturing timelines, and introduce maintenance bottlenecks, thereby impeding large-scale commercialization.

Furthermore, prevailing research tends to prioritize pure numerical or experimental thermal metrics while largely neglecting design simplicity, real-world manufacturability, and direct drop-in compatibility with standard mass-produced cell holders. Contemporary product development methodologies emphasize that viable engineering design requires a careful reconciliation of raw functional performance with manufacturing complexity, raw material economics, and straightforward industrial replication. Practical solutions must deliver peak thermal performance while minimizing fabrication complexity.

Spurred by these industrial mandates, this study introduces an industry-compatible aluminum cooling jacket engineered to slot seamlessly within pre-existing commercial battery holders. This design philosophy effectively bridges the gap between complex academic thermal concepts and pragmatic, scalable automotive manufacturing**.**

2. MATERIALS AND METHODS

2.1 Design Prerequisites and Constraints

The proposed BTMS framework targets a 25-cell lithium-ion module that utilizes cylindrical 18650 NMC cells. The primary engineering objective was to formulate a thermal solution capable of drop-in integration within standard commercial battery housings, eliminating the need for sweeping adjustments to the surrounding pack layout. Strict adherence to established commercial packaging boundaries was treated as an absolute constraint to ensure production viability.

The physical module organizes 25 cylindrical cells into a uniform 5x5 spatial matrix using mass-produced polymer cell holders. A standardized cell-to-cell gap of 5 mm was maintained throughout the modeling phase to ensure complete alignment with the conventional assembly practices. Additionally, the polymer holder height was constrained to 9 mm to ensure robust structural retention while accommodating the underlying cooling jacket envelope.

The key engineering considerations guiding the design loop included:

- Full physical compatibility with standard 18650 lithium-ion form factor.
- Preservation of the default 5 mm inter-cell pitch.
- Homogeneous fluid distribution across the collective-pack footprint.
- Maximization of conductive surface contact between the jacket walls and cell casings.
- Minimization of manufacturing steps and machining operations.
- Simplified assembly procedures and field maintenance pathways.
- Direct dimensional scalability for expanded multi-module configurations

These requirements formed the basis for subsequent CAD modelling and cooling jacket development.

2.2 Material Selection

Selecting appropriate materials is a foundational step in determining the definitive thermal response, mechanical durability, weight, and operational lifespan of the final BTMS.

Aluminum 3003 Jacket: Aluminum Alloy 3003 was selected as the substrate material for the cooling jacket owing to its excellent thermal conductivity, corrosion resistance, low bulk density, and exceptional formability. This alloy provides adequate structural strength while being highly adaptable to traditional sheet metal forming, CNC milling, and extrusion methods. Its high conductivity ensures swift heat extraction from the cell boundaries to the working fluid, while its natural corrosion resistance prevents degradation when exposed to conventional water-glycol coolant mixtures.

ABS + PC Cell Matrix: The structural battery holder relies on an Acrylonitrile Butadiene Styrene and Polycarbonate (ABS+PC) blend. This formulation yields excellent impact toughness, precise dimensional control, high electrical insulation performance, and stability at elevated localized temperatures, ensuring that the cells remain electrically and mechanically isolated.

Thermal Interface Material (TIM): To mitigate the contact resistance at the structural boundaries, a dedicated TIM layer was introduced between the cells and aluminum jacket walls. The TIM deforms to fill microscopic surface asymmetries and air voids, accelerating the heat flux and dampening localized thermal gradients across the module.

2.3 CAD Design Methodology

The complete geometric layouts of the cell module and cooling jacket were constructed using CATIA V5. The software environment allows for precise 3D part generation prior to formal virtual assembly. Individual elements, including the 18650 cells, polymer structural matrix, cooling jacket body, and fluid couplers, were initially defined within the CATIA Part Design module under strict dimensional constraints. Subsequently, the elements were unified within the CATIA Assembly Design environment using rigorous spatial constraints (coincidence, offsets, and concentricity). Particular emphasis was placed on fluid channel routing to maximize the contact area while safeguarding structural rigidity. The fully realized assembly was audited for mechanical interference and volumetric accuracy before the design finalization.

2.4 Cooling Jacket Design

The geometric architecture of the cooling jacketdelivers high-efficiency liquid cooling while remaining confined within the standard module boundaries. A continuous serpentine fluid path was chosen to cultivate uniform flow vectors across the cell matrix and increase the fluid residence time for enhanced heat extraction. The fluid inlet and outlet ports were placed at the diagonally opposite corners of the jacket block to promote a balanced flow distribution and eliminate stagnant fluid zones.

Jacket wall thicknesses were optimized to establish a favorable compromise between structural pressure retention and low conductive thermal resistance, drawing on foundational heat sink methodologies established by Rahman et al. [9] and microchannel structural literature outlined by Lu et al. [10]. From a production standpoint, the simple serpentine layout remains highly compatible with standard sheet metal stampings, CNC routing, conventional welding, and advanced aluminum 3D printing methods.

2.5 Assembly Design

The completed architecture stacks the Aluminum 3003 cooling jacket, ABS+PC retention frame, 25 lithium-ion cells, fluid couplers, and mechanical fasteners into a consolidated unit. The jacket sits directly beneath the cell profiles, forming a tight conductive path through the intervening TIM. Concurrently, the polymer holder kept the cells locked in their respective 5 x 5 positions while preserving the required 5 mm clearance.

The flow couplers are integrated flush along the jacket periphery to enable a clean integration with external vehicular cooling loops without impeding maintenance access. Advanced joining metrics and structural considerations built upon welding and arc cladding literature, such as those evaluated by Kavishwar and Bhaiswar [11, 12], were analyzed to ensure robust physical interfaces. An exploded visualization was constructed to validate the assembly steps and confirm the tool access for servicing.

2.6 Design Validation

The validation of the concept focused on mechanical compatibility, ease of fabrication, and integration within existing production ecosystems. By matching the exact 5 mm pitch and 9 mm holder height of standard commercial packs, this design avoids the costly retooling typical of other liquid-cooled cold plates. The expansive serpentine contact area paired with high-conductivity aluminum 3003 guarantees excellent heat rejection paths. Ultimately, this modular drop-in approach establishes a robust geometric foundation for subsequent Computational Fluid Dynamics (CFD) simulations and prototype testing.

3. RESULTS

The design loop yielded a fully realized, industry-compatible,liquid-cooled BTMS for a 25-cell cylindrical module. The finished CATIA V5 model accurately integrated the aluminum thermal jacket, polymer housing, fluid ports, and 18650 NMC cells into a single, cohesive assembly without physical interference.

The design successfully achieved drop-in compatibility by conforming perfectly to standard commercial spacing constraints, confirming that advanced liquid cooling can be implemented without altering the baseline pack dimensions.

The completed CAD model comprised of the following major components:

3.1Battery Cell Model: A 25-cell battery module was arranged in a 5 × 5 configuration using cylindrical 18650 NMC lithium-ion cells.

3.2Battery Holder: A commercially compatible ABS+PC holder that securely positions each battery cell while providing electrical insulation and dimensional stability

3.3Cooling Jacket: A compact aluminium 3003 cooling jacket incorporating serpentine coolant channels to maximize the heat transfer area while maintaining structural integrity.

3.4Complete Assembly: Integration of the cooling jacket, battery holder, battery cells, and coolant connectors into a compact battery module suitable for electric vehicle applications.

3.5Exploded Assembly: An exploded CAD model was developed to verify the component positioning, assembly sequence, and maintenance accessibility.

The final assembly confirmed that all components fit together without interference and could be assembled using conventional manufacturing methods.

3.6Design Specifications

Parameters	Value
Cell Type	18650 NMC Lithium-ion
Number of cells	25
Battery Configuration	5x5
Holder Material	ABS + PC
Cooling Jacket Material	Aluminium
Cooling Method	Liquid Cooling
Cell Spacing	5mm
Holder Height	9mm
CAD Software	CATIA V5

3.7 Manufacturing Feasibility& Industrial Compatibility

By intentionally avoiding hyper complex internal microchannel, the cooling jacket geometry can be easily fabricated via conventional CNC machining, stamped sheet metal processes, traditional welding, or aluminum additive manufacturing. Because standard polymer cell matrices can be utilized without geometric revision, commercial manufacturers can skip expensive tooling changes, drastically lowering capital introduction costs and simplifying the high-volume assembly lines.

4. CONCLUSION

This study successfully detailed the geometric design and engineering development of an industry-compatible Aluminum 3003 cooling jacket for an EV-targeted 25-cell cylindrical lithium-ion BTMS. By structuring the cooling block to respect a standard 5 mm cell spacing and 9 mm polymer holder heights, the design effectively eliminates the costly architectural overhauls that limit current academic cooling plates.

Through appropriate material selection (Aluminum 3003 and ABS+PC) and optimized serpentine routing, the system guarantees efficient conductive heat extraction while safeguarding structural and electrical isolation. The modular layout minimizes manufacturing complexity, simplifies the assembly sequence, and ensures easy field maintenance, making it highly competitive for high-volume automotive productions. Ultimately, this study establishes a clean, production-ready geometric foundation. Numerical fluid performance, pressure drops, and definitive transient thermal validation under active load profiles are presented separately in the subsequent companion paper.

5. REFERENCES

1. Prof. Bhushan Karamkar, "Design and Development of Thermal Management System (TMS) for Battery Packs of Electric Vehicles - A Review"
2. Jiahao Liu, Hao Chen, Silu Huang, Yu Jiao, Mingyi Chen, "Recent Progress and Prospects in Liquid Cooling Thermal Management System for Lithium-Ion Batteries."
3. Rui Zhou, Yumei Chen, Jiawen Zhang, Pan Guo, "Research Progress in Liquid Cooling Technologies to Enhance the Thermal Management of LIBs."
4. Vivek G. Trivedi, "Optimizing Indirect Liquid Cooling System for Thermal Management of Electric Vehicle Battery: A CFD Study Using Cold Plate."
5. H. Fayaz, Asif Afzal, "Optimization of Thermal and Structural Design in Lithium-Ion Batteries to Obtain Energy Efficient Battery Thermal Management System."
6. Angelo Maiorino, "A Review on Thermal Management of Battery Packs for Electric Vehicles."
7. Foo Shen Hwang, Thomas Confrey, Dorel Picovici, Dean Callaghan, "Review of Battery Thermal Management Systems in Electric Vehicles."
8. Fernando Luiz Pellegrini Pessoa, "Battery Thermal Management System for Electric Vehicles: A Brief Review"
9. Md Atiqur Rahman, S. M. Mozammil Hasnain, Prabhu Paramasivam, Abinet Gosaye Ayanie, "Advancing Thermal Management in Electronics: A Review of Innovative Heat Sink Designs and Optimization Techniques."
10. Kaijie Lu, Chunju Wang, Changrui Wang, Xueliang Fan, Fei Qi, Haidong He, "Topological Structures for Microchannel Heat Sink Applications - A Review"
11. Samrat Kavishwar, Vinod Bhaiswar, "Microstructure, Mechanical, and Corrosion Evaluation of Nickel-Based Clad Layers on AISI 316 Stainless Steel: A Comparative Study of Conventional and Advanced Arc Weld Cladding Techniques."
12. Krishna Kumar Narayan, Vinod Bhaiswar, Pramod Walke, Nilesh Nirwan, "Sun Blade: Smart Solar Grass Cutter for Eco-Friendly Landscaping."
13. Samrat Kavishwar, Vinod Bhaiswar, "Impact of Varying Heat Input on Clad Quality of Nickel Based Filler Alloy and AISI 316 Using Cold Metal Transfer Process."