IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁑ Peer-reviewed & Refereed journal ⁑ Vol. 15, Issue 5, May 2026

DOI: 10.17148/IJARCCE.2026.155152

Optimised Battery Thermal Management System: Design and Thermal Analysis Review

Syed Mohammd Ashfaque[1], C Mohhammad Asif [2], Shaik Naveed [3], Altaf [4]

U.G. Student's, Department of Mechanical Engineering, BITM, Ballari, Karnataka, India[1-4]

INTRODUCTION

The rapid transition toward electric mobility is driven by the urgent need to reduce greenhouse gas emissions and dependency on fossil fuels [1]. At the core of this transition are Lithium-ion batteries, favored for their high energy density and specific power [1]. However, these batteries are highly sensitive to temperature; their optimal operating range is typically between 15°C and 35°C [1]. Operating outside this range can lead to accelerated degradation, reduced range, and catastrophic thermal runaway events [2]. Consequently, a robust Battery Thermal Management System is essential to maintain temperature uniformity and prevent excessive heat buildup during high charge-discharge cycles [3]. This study focuses on designing and analyzing an optimized BTMS to enhance cooling efficiency and safety for modern electric vehicles.

LITERATURE REVIEW

Recent research highlights several cooling strategies, each with distinct advantages and limitations.

Air Cooling: Traditionally favored for its simplicity and low cost, air cooling often struggles with poor temperature uniformity [4]. Innovations such as step-like divergence plenums in Z-type systems have been shown to reduce maximum temperatures by approximately 3.94 K and temperature differences by 5.93 K compared to standard models [5].

Liquid Cooling: This method offers high heat transfer rates and is effective for high-power applications, though it adds complexity and weight [4]. Optimization of cooling plate designs and channel geometries is a primary research focus to balance cooling performance with pumping power [6].

Phase Change Materials: PCMs like paraffin provide excellent passive cooling by absorbing latent heat, but their low thermal conductivity often requires enhancement with metal foams or fins [7].

Hybrid Systems: Emerging trends suggest that combining liquid cooling with PCMs or thermoelectric coolers provides the most robust solution for high-performance applications, such as racing cars, by balancing thermal efficiency with structural compactness [7], [8].

METHODOLOGY

The optimization of the BTMS follows a structured Computational Fluid Dynamics and experimental workflow:

Geometric Modeling: CAD models of the battery pack and cooling channels are developed using software like SOLIDWORKS [9].

Numerical Simulation: The CAD models are imported into CFD environments (e.g., ANSYS Fluent, STAR-CCM+, or COMSOL) where the fluid domain and battery cells are discretized into high-density meshes [6], [9]. For instance, precise thermal analysis may involve millions of elements to ensure accuracy [10].

Boundary Conditions: Heat generation rates are determined using equivalent circuit models that reflect electrochemical actions during various driving cycles [10], [11].

Validation: Simulation results are validated against bench tests using thermal dummy cells or real Li-ion modules equipped with thermocouples [12], [13]. Recent studies report high correlation between simulated and experimental data, with maximum temperature deviations as low as 1.8% [12].

DOI: 10.17148/IJARCCE.2026.155152

RESULTS

The thermal analysis of the optimized system reveals significant performance improvements. Simulations of a liquid-cooled BTMS utilizing a water-glycol mixture demonstrated that average cell temperatures could be maintained near 31°C, even under high thermal loads [10]. Optimization of cooling fluid velocity and inlet temperature led to a 16% reduction in overall cell temperature [10]. In air-cooled configurations, the implementation of a 7-step plenum design achieved a cell temperature difference of only 1 K, significantly improving uniformity across the pack [5]. Furthermore, hybrid liquid-PCM configurations were found to markedly reduce over-temperatures compared to purely passive or air-cooled systems, maintaining safety even in ambient temperatures up to 35°C [8].

DISCUSSION

The results underscore the trade-offs inherent in BTMS design. While air cooling is the most cost-effective, its reliance on high inlet velocities to achieve uniformity increases pumping power requirements [5]. Liquid cooling provides superior heat dissipation (up to 386.5 W in simulated modules) but requires careful management to prevent leakage and electrical shorts [4], [10]. The integration of PCMs offers a "buffer" during peak heat generation but may be limited by the weight of the material and its inability to reject heat continuously without an active secondary system [7]. Optimization through CFD allows designers to identify the "sweet spot" where temperature gradients are minimized without excessive energy consumption [3], [7].

CONCLUSION

This research demonstrates that optimizing the geometry of cooling channels and utilizing hybrid cooling methods are vital for the next generation of EVs. An optimized liquid-cooled or hybrid liquid-PCM system effectively keeps Li-ion batteries within their ideal thermal window, thereby prolonging battery life and enhancing vehicle safety. Future work should focus on integrating intelligent control algorithms and novel high-conductivity materials to further refine BTMS efficiency and reduce system weight [6], [11].

REFERENCES

1. Tang, A.; Li, J.; Lou, L.; Shan, C.; Yuan, X. Optimization design and numerical study on water cooling structure for power lithium battery pack. Appl. Therm. Eng. 2019, 159, 113760. [CrossRef].
2. Zhuang, W.; Liu, Z.; Su, H.; Chen, G. An intelligent thermal management system for the optimized lithium-ion battery pack. Appl. Therm. Eng. 2021, 189, 116767. [CrossRef]
3. Park, S.; Jang, D.S.; Lee, D.; Hong, S.H.; Kim, Y. Simulation on cooling performance characteristics of a refrigerant-cooled active thermal management system for lithium ion batteries. Int. J. Heat Mass Transf. 2019, 135, 131–141. [CrossRef]
4. Park, S.; Lee, H.; Park, C.; An, J.; Kim, C.-W. Optimization using kriging metamodel and CMA-ES to improve temperature uniformity of Electric Vehicle liquid-cooled cylindrical Li-ion battery BTMS. J. Comput. Des. Eng. 2025, 12, 167–178. [CrossRef]
5. Pires, R.A., Jr.; Carvalho, S.A.; Cardoso Filho, B.J.; Pires, I.A.; Huebner, R.; Maia, T.A. The Assessment of Electric Vehicle Storage Lifetime Using Battery Thermal Management System. Batteries 2022, 9, 10. [CrossRef]
6. Xie, Y.; Wang, C.; Hu, X.; Lin, X.; Zhang, Y.; Li, W. An MPC-based control strategy for electric vehicle battery cooling considering energy saving and battery lifespan. IEEE Trans. Veh. Technol. 2020, 69, 14657–14673. [CrossRef]
7. Li, M.; Wang, J.; Guo, Q.; Li, Y.; Xue, Q.; Qin, G. Numerical analysis of cooling plates with different structures for electric vehicle battery thermal management systems. J. Energy Eng. 2020, 146, 04020037. [CrossRef]
8. Liu, F.-F.; Lan, F.-C.; Chen, J.-Q.; Li, Y.-G. Experimental investigation on cooling/heating characteristics of ultra-thin micro heat pipe for electric vehicle battery thermal management. Chin. J. Mech. Eng. 2018, 31, 1–10. [CrossRef]
9. Akinlabi, A.H.; Solyali, D. Configuration, design, and optimization of air-cooled battery thermal management system for electric vehicles: A review. Renew. Sustain. Energy Rev. 2020, 125, 109815. [CrossRef]
10. 10. Xie, J.; Ge, Z.; Zang, M.; Wang, S. Structural optimization of lithium-ion battery pack with forced air cooling system. Appl. Therm. Eng. 2017, 126, 583–593. [CrossRef]