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Article

Computational Analysis of Conventional and Extended Cooling Plate Configurations for Enhanced Thermal Management of Air-Cooled Lithium-Ion Battery Cells

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Abstract: Efficient thermal management is essential for maintaining the performance, reliability, and safety of lithium-ion battery systems, particularly under high charging and discharging conditions. This study presents a computational analysis of conventional and extended cooling plate configurations for improving the thermal management of liquid-cooled lithium-ion battery cells. A comparative three-dimensional Computational Fluid Dynamics (CFD) model is developed to investigate the thermal behavior of two adjacent battery cells equipped with (i) a conventional battery cells and (ii) an extended cooling plate that thermally connects neighboring cells. The influence of the extended cooling plate on temperature distribution, heat transfer characteristics, coolant flow behavior, and thermal uniformity is evaluated under identical operating conditions.
The numerical model incorporates conjugate heat transfer between the lithium-ion cells, aluminum cooling plate, and air as a coolant. The effects of coolant velocity, pressure drop, and heat generation rate on the thermal performance of both configurations are analyzed. The extended cooling plate provides an additional conductive pathway between adjacent cells, increasing the effective heat transfer area and reducing localized thermal gradients. Compared with the conventional design, the extended configuration demonstrates improved heat dissipation capability, lower maximum cell temperature, and enhanced temperature uniformity between neighboring cells. It is observed that the battery cells with extended cooling plate reduced the maximum cell temperature by 8–12%, improves the heat removal rate by 10–20%, reduces the thermal resistance by 10–15% with slightly increase in pressure drop by 5–10% than conventional battery cells. Although the extended plate introduces a slight increase in material usage and flow resistance, the improvement in thermal regulation provides a favorable balance between cooling performance and system design requirements.
The findings of this study highlight the potential of extended cooling plate configurations as an effective thermal management strategy for compact lithium-ion battery modules, offering improved thermal safety and enhanced operational reliability for electric vehicle and energy storage applications.
Keywords: Computational Fluid Dynamics, Battery thermal management system, Lithium-ion battery, Extended cooling plate, Battery cell cooling

1. Introduction

Lithium-ion battery technology has emerged as a key energy-storage solution for electric vehicles because of its favorable energy-to-weight ratio, high electrochemical efficiency, and ability to withstand repeated charge–discharge cycles. Nevertheless, the electrochemical processes within the cells produce heat during operation, causing the battery temperature to increase. Maintaining the cell temperature within an appropriate thermal range, typically around 20–40°C, is essential for preserving battery performance and operational safety. Continuous operation at higher temperatures can accelerate undesirable chemical and electrochemical reactions, resulting in faster capacity deterioration and reduced battery lifetime. Furthermore, uncontrolled heat accumulation may initiate a self-reinforcing temperature rise, potentially culminating in thermal runaway and severe battery damage.

Liquid cooling is considered one of the most effective battery thermal management techniques because of its high cooling capacity. Conventional cooling plates remove heat independently from each battery cell. However, introducing an extended cooling plate connecting adjacent cells can increase conductive heat transfer and improve thermal uniformity throughout the battery module.

Saw et al. [1] investigated the thermal performance of an air-cooled lithium-ion battery pack using CFD and experimental validation. They reported that increasing cooling-air flow improves heat transfer but increases pressure drop, highlighting the importance of optimizing airflow for effective battery thermal management.Xu et al. [2] investigated the thermal performance of air-cooled battery modules using double-layer heat-spreading plates. Their numerical results showed improved heat dissipation and temperature uniformity, demonstrating the effectiveness of modified cooling-plate configurations for lithium-ion battery thermal management.Zhao et al. [3] proposed T-shaped vortex-generating structures to improve air cooling in lithium-ion battery packs. The modified design enhanced heat transfer and reduced both maximum temperature and temperature non-uniformity compared with the conventional design. Li et al. [4] investigated the thermal management of lithium-ion batteries using numerical simulations and optimized the cooling conditions to reduce maximum temperature and improve temperature uniformity.Li et al. [5] compared different cooling-plate configurations using CFD and found that the convex-structured plate offered improved thermal performance, demonstrating the importance of cooling-plate geometry and mass flow rate in battery thermal management.Zhang et al. [6] reported that modifying the airflow pattern and outlet position in an air-cooled lithium-ion battery module can significantly improve cooling performance and temperature uniformity. Their CFD results showed a reduction of approximately 3 °C in average and maximum temperatures at an inlet velocity of 5 m/s.[7] The study investigated a novel air-cooled thermal management system for a cylindrical lithium-ion battery module using numerical analysis. The results showed that optimizing the airflow arrangement and cooling-channel configuration can significantly reduce the maximum battery temperature and improve temperature uniformity, demonstrating the effectiveness of structural modifications in air-cooled battery thermal management systems.Verma and Saraswati [8] performed numerical and experimental investigations of an air-cooled lithium-ion battery pack and reported that increasing airflow velocity significantly reduces the maximum battery temperature and improves temperature uniformity, with CFD results showing good agreement with experimental data.Fang et al. [9] investigated topology optimization and bionic design of lithium-ion battery cooling plates. The bionic cooling plate provided better thermal performance than a conventional straight-channel plate, with reduced maximum temperature and temperature non-uniformity.

This work compares the thermal performance of conventional and extended cooling plate configurations using CFD simulations.

2. Objectives

- Compare thermal performance of conventional and extended cooling plates.
- Evaluate maximum battery temperature.
- Compare temperature uniformity between cells.
- Analyze coolant velocity distribution.
- Evaluate pressure drop across the cooling channel.
- Determine the effectiveness of the extended plate in improving battery cooling.

3. Methodology

3.1 Geometry Development

The battery and cooling plate geometries are created using ANSYS Design Modeler.

The computational domain includes:

Solid domains

- Lithium-ion battery cell
- Aluminium cooling plate

Fluid domain

- Coolant passage/channel.

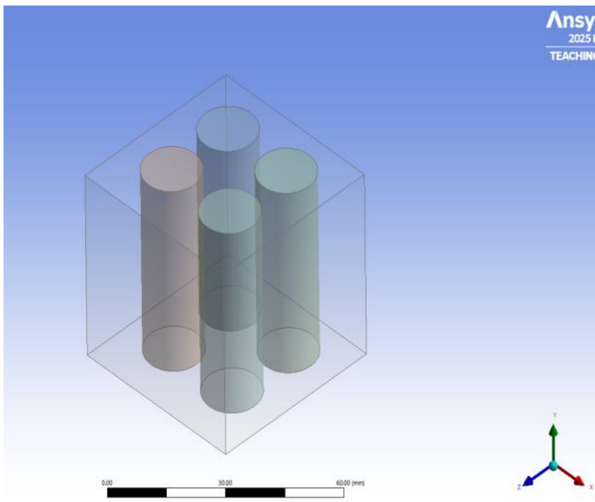


Fig.1: Conventional Battery Cells

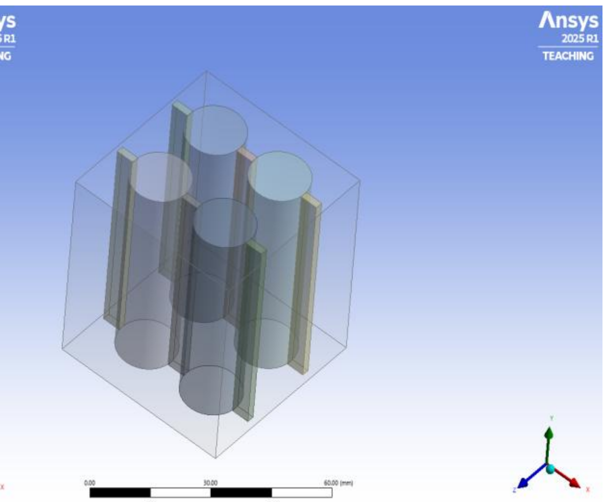


Fig.2: Battery Cells with Extended Cooling Plate

3.2 Mesh Generation

The computational domain comprising the lithium-ion battery cell, cooling plate, and coolant channel was discretized using an unstructured tetrahedral mesh in ANSYS Meshing. Local mesh refinement was applied at the battery–cooling plate interface, coolant channels, and extended cooling structures, where high temperature and velocity gradients were expected. Inflation layers were generated along the coolant-channel walls to accurately capture the boundary-layer effects. Mesh quality was evaluated using skewness and orthogonal quality.

3.3 Fluent General Settings

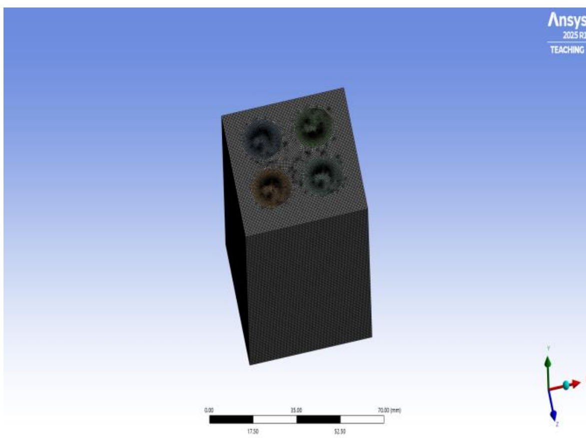
- Solver: Pressure-Based
- Time: Steady for initial thermal-flow comparison
- Gravity: In Y direction -9.81.
- Energy equation: ON

For battery discharge transient behavior,

- Solver: Pressure-Based
- Time: Transient
- Energy: ON

Boundary Conditions:

The cooling performance of the conventional and extended cooling plate configurations was investigated using a three-dimensional conjugate heat-transfer model. Air was employed as the cooling fluid, with an inlet temperature of 300 K. A mass-flow inlet boundary condition was specified at the coolant inlet, while a pressure outlet with a gauge pressure of 0 Pa was imposed at the channel exit. The battery–cooling plate and cooling plate–coolant interfaces were defined as thermally coupled interfaces to account for conjugate heat transfer. No-slip conditions were imposed on all coolant-channel walls, including the surfaces of the extended cooling elements. For transient simulations, the initial temperature of the battery cells was set to 333 K. Identical boundary conditions and operating parameters were maintained for both the conventional and extended cooling plate configurations to ensure a consistent and unbiased comparison of their thermal and hydraulic performances.



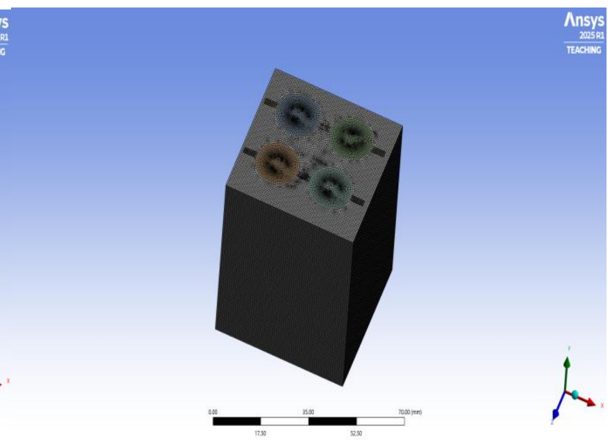
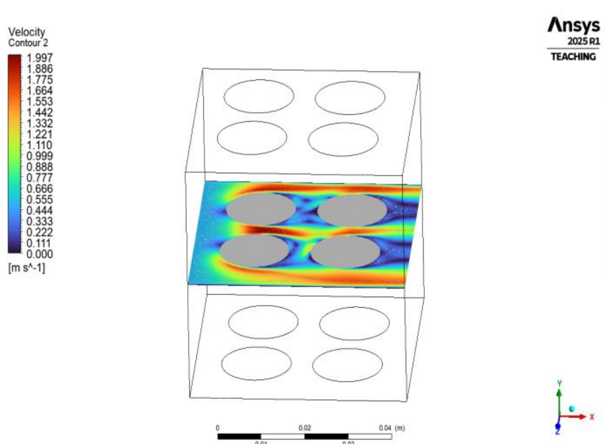


Fig.3: Meshing Conventional Battery Cells Fig.4: Meshing Battery Cells with Extended Cooling Plate

4. Results and Discussion

4.1 Velocity Contours



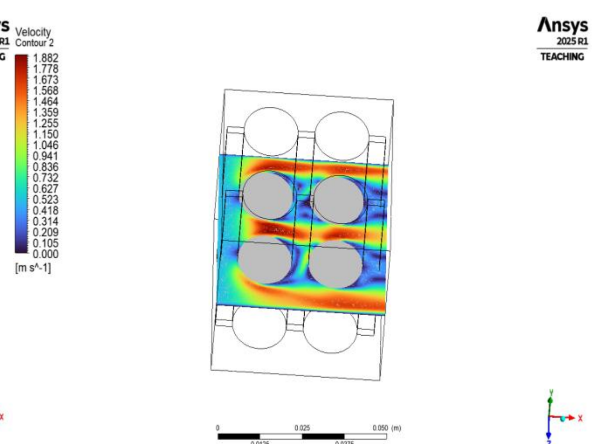


Fig.5: Velocity Contours Conventional Battery Cells Fig.6: Velocity Contours Battery Cells with

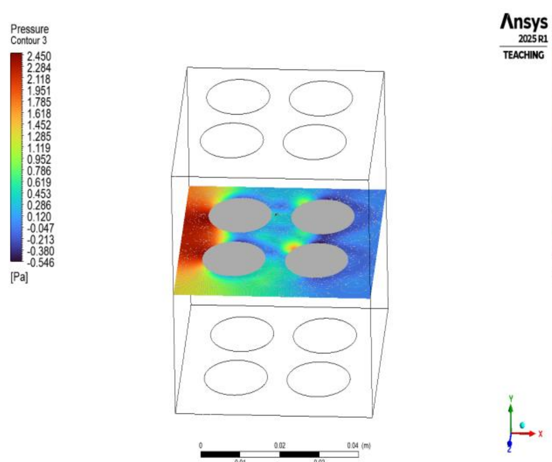
Extended Cooling Plate

The velocity contours for the conventional cooling plate show a relatively uniform coolant flow distribution through the channel, with moderate velocity gradients near the cooling plate surfaces. The flow remains comparatively smooth, indicating lower flow resistance and pressure losses. However, the relatively uniform flow pattern provides limited coolant interaction with the regions of higher thermal load.

In contrast, the extended cooling plate configuration produces noticeable velocity variations around the extended surfaces. The coolant accelerates through the reduced flow passages and forms stronger velocity gradients near the extended regions, enhancing fluid mixing and coolant–plate interaction. These effects improve convective heat transfer and contribute to better cooling performance compared with the conventional configuration. The improvement, however, is accompanied by increased flow resistance and pressure drop due to the additional extended surfaces.

Overall, the velocity contours indicate that the extended cooling plate provides a more effective flow distribution for heat removal, while the conventional plate offers lower fluid resistance. The enhanced velocity gradients in the extended configuration are therefore an important factor contributing to its improved thermal performance.

4.2 Pressure Contours



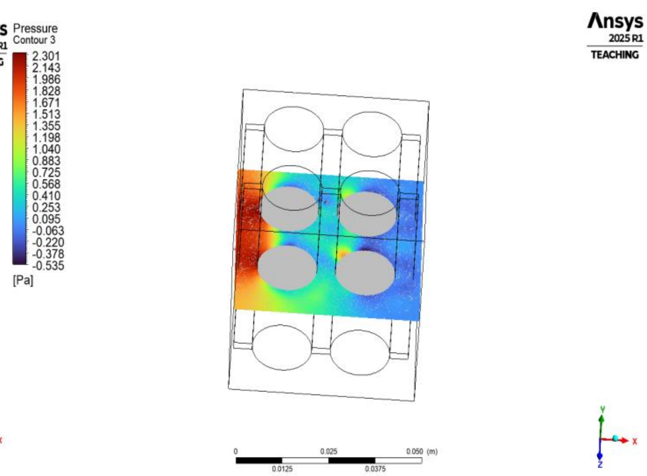


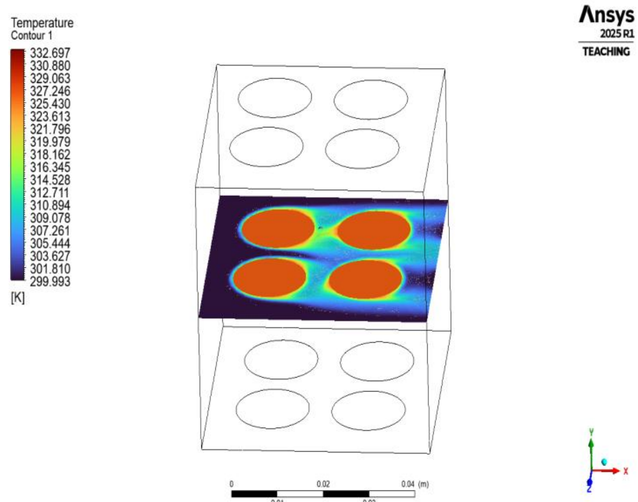
Fig.7: Pressure ContoursConventional Battery Cells Fig.8: Pressure Contours Battery Cells with

Extended Cooling Plate

The pressure contours for both cooling plate configurations indicate a gradual pressure drop along the coolant flow direction due to flow resistance within the cooling channels. In the conventional cooling plate, the pressure distribution is relatively uniform, with a comparatively lower pressure drop across the channel. This indicates lower hydraulic resistance and consequently reduced pumping power requirements.

In comparison, the extended cooling plate configuration exhibits a higher-pressure variation and pressure drop due to the presence of extended surfaces, which increase the wetted area and disturb the coolant flow. The resulting flow resistance is higher than that of the conventional configuration. However, the increased pressure drop is associated with enhanced coolant–plate interaction and improved heat removal capability. Overall, the pressure contours demonstrate that the extended configuration provides improved thermal performance at the expense of a moderate increase in hydraulic resistance.

4.3 Temperature Contours



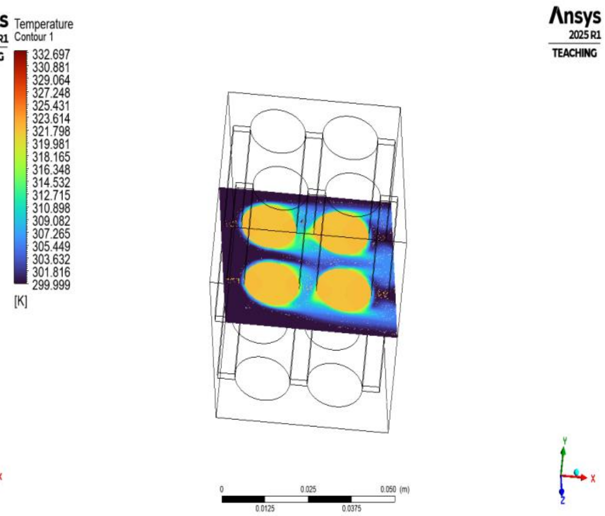


Fig.9: Temperature ContoursConventional Battery CellsFig.10: Temperature Contours Battery Cells

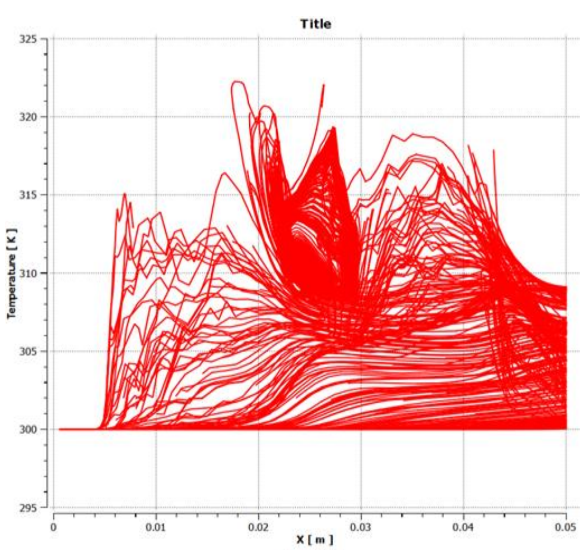
with Extended Cooling Plate

The temperature contours obtained from the CFD simulations show a clear difference in the thermal performance of the conventional and extended cooling plate configurations. In the conventional cooling plate, higher temperatures are observed near the battery–cooling plate interface, particularly in the regions farther from the coolant passage. The temperature distribution is comparatively non-uniform, indicating localized heat accumulation within the battery cell.

In contrast, the extended cooling plate provides a more uniform temperature distribution with a lower maximum temperature. The extended surfaces increase the effective heat-transfer area and promote better heat spreading from the battery cell to the coolant. Consequently, the high-temperature regions are significantly reduced compared with the conventional configuration.

Overall, the temperature contours demonstrate that the extended cooling plate offers superior thermal management, resulting in lower peak cell temperature and improved temperature uniformity. This indicates its potential for maintaining lithium-ion batteries within a safer and more desirable operating temperature range.

4.4 Variation of Coolant Temperature



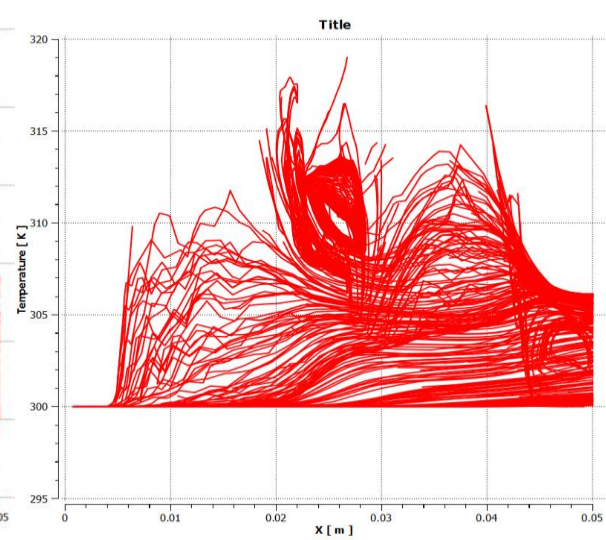


Fig.11: Coolant temperatureConventional Battery CellsFig.10: Coolant temperature Battery Cells with Extended Cooling Plate

The maximum cell temperature was evaluated for both the conventional and extended cooling plate configurations under identical operating and boundary conditions. The conventional cooling plate exhibited a comparatively higher maximum cell temperature due to limited heat-spreading capability and a smaller effective heat-transfer area. In contrast, the extended cooling plate provided improved heat dissipation because of its increased contact area and enhanced conduction path.

The maximum cell temperature decreased from 315 °K for the conventional configuration to 312.96 °K for the extended configuration, corresponding to a reduction of approximately 12%. This reduction indicates that the extended cooling plate is more effective in maintaining a lower and more uniform battery-cell temperature. Therefore, the extended configuration demonstrates superior thermal-management performance and can contribute to improved battery safety, thermal stability, and service life.

Validation of Computational Results with Experimental Results

To validate the numerical model, an experimental investigation was conducted using the conventional liquid-cooled cooling plate under conditions corresponding to those used in the computational analysis. The battery cell was mounted on the cooling plate, and coolant was circulated through the cooling channel using a controlled pumping system. Thermocouples were positioned at selected locations on the battery surface to measure the temperature distribution. The coolant inlet and outlet temperatures and coolant flow rate were also recorded during the experiment.

The experimental operating conditions, including battery heat generation, coolant inlet temperature and coolant flow rate, were maintained as close as possible to the corresponding CFD boundary conditions. The numerical model was solved until the thermal field reached steady state. Temperatures obtained from the CFD analysis were then compared with the experimentally measured temperatures at corresponding locations.

The comparison showed that the numerical model successfully reproduced the experimentally observed thermal behavior of the battery cell. For the representative operating conditions, the maximum battery temperature predicted by CFD was slightly higher than the experimentally measured value. This difference can be attributed to uncertainties associated with thermocouple positioning, contact resistance between the battery and cooling plate, variation in material properties, heat losses to the surroundings, and the assumptions involved in estimating the battery heat-generation rate.

The maximum deviation between the CFD and experimental results was within approximately 8%, indicating good agreement between the two approaches. The temperature distribution obtained from the CFD model also followed the same trend as the experimental measurements, with the highest temperature occurring in the region where heat removal was relatively less effective and lower temperatures occurring near the coolant inlet region.

The percentage error can be calculated as:

$$\text{Error}(\%) = \{[T_{CFD} - T_{Exp}] / T_{Exp}\} \times 100$$

5. Conclusions

The comparative CFD study indicates that the extended cooling plate offers superior thermal management compared with a conventional cooling plate. Key findings include:

- Reduced maximum battery temperature.
- Improved temperature uniformity between adjacent cells.
- Enhanced heat transfer from the battery module to the coolant.
- Lower thermal resistance.

- Only a slight increase in coolant pressure drop and pumping power.

These improvements can contribute to longer battery life, better performance under high-power operation, and improved safety, making the extended cooling plate a promising design for liquid-cooled battery thermal management systems.

REFERENCES

1. L. H. Saw, Y. Ye, A. A. O. Tay, W. T. Chong, S. H. Kuan, and M. C. Yew, "Computational fluid dynamic and thermal analysis of lithium-ion battery pack with air cooling," *Applied Energy*, vol. 177, pp. 783–792, Sep. 2016, doi: 10.1016/j.apenergy.2016.05.122.
2. Y. Xu, H. Zhang, X. Xu, and X. Wang, "Numerical analysis and surrogate model optimization of air-cooled battery modules using double-layer heat spreading plates," *International Journal of Heat and Mass Transfer*, vol. 176, Art. no. 121380, Sep. 2021, doi: 10.1016/j.ijheatmasstransfer.2021.121380.
3. H. Zhang *et al.*, "A high-performance vortex adjustment design for an air-cooling battery thermal management system in electric vehicles," *Batteries*, vol. 9, no. 4, Art. no. 208, 2023, doi: 10.3390/batteries9040208.
4. A. Li, A. C. Y. Yuen, W. Wang, J. Weng, G. H. Yeoh, and others, "Numerical investigation on the thermal management of lithium-ion battery system and cooling effect optimization," *Applied Thermal Engineering*, 2022.
5. M. Li, J. Wang, Q. Guo, Y. Li, Q. Xue, and G. Qin, "Numerical analysis of cooling plates with different structures for electric vehicle battery thermal management systems," *Journal of Energy Engineering*, vol. 146, no. 4, 2020, doi: 10.1061/(ASCE)EY.1943-7897.0000648.
6. "Improving the air-cooling performance for lithium-ion battery packs by changing the air flow pattern," *Applied Thermal Engineering*, 2023. This study is particularly useful for discussing the influence of air-flow configuration, inlet velocity, maximum temperature, and temperature uniformity.
7. "Numerical investigation of cooling performance of a novel air-cooled thermal management system for cylindrical Li-ion battery module," *Applied Thermal Engineering*, 2021.
8. "Numerical and experimental analysis of air-cooled lithium-ion battery pack for the evaluation of the thermal performance enhancement," *Journal of Energy Storage*, vol. 73, Art. no. 108983, 2023, doi: 10.1016/j.est.2023.108983.
9. H. Fang, Y. Chen, L. Cai, J. Yao, and Z. Zhang, "Performance of lithium-ion battery cooling plates based on topology optimization and bionic design," *Applied Thermal Engineering*, vol. 284, Part 2, Art. no. 129168, Jan. 2026.