Original Research Paper

Thermal Modeling of Blade Lithium Iron Phosphate Battery with Liquid Cooling and Addition of Manganese to Cathode

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Abstract: Electric vehicles are a key alternative to fossil fuel-based transportation but face challenges in safety and driving range. Blade battery technology, with its long and flat shape, offers improved heat distribution and safety. This study focuses on the thermal performance of a blade-shaped Lithium Iron Phosphate (LFP) battery enhanced with manganese (LMFP), using a water-based cooling system to ensure temperature stability during operation. Effective thermal management, including the use of cooling systems, is crucial for maintaining battery performance and reliability. This study modeled a blade-shaped battery with a water-cooling system using ANSYS Fluent. The process involves designing 3D geometry and meshing to simulate thermal behavior accurately. The simulation was conducted under varying operating conditions by applying different inlet temperatures for the cooling system (14.85°C, 26.85°C, and 34.85°C) combined with different discharge rates (0.5C, 1C, 2C, and 5C). These parameter variations were designed to evaluate the thermal response of the battery under realistic and dynamic working environments. The results indicate that the cooling system can maintain the battery temperature within the optimal thermal range, with the maximum temperature remaining below 35°C across all tested conditions. Higher C-rates resulted in increased internal heat generation, leading to higher cell temperatures. This study contributes to the development of thermally stable, higher-energy-density batteries, offering practical insights for designing safer and more efficient battery packs in electric vehicles.

Keywords: Blade Battery, Electric Vehicle, Liquid Cooling System, Lithium Manganese Iron Phosphate, Thermal Performance.

1. Introduction

The burning of fossil fuels in vehicles significantly contributes to carbon emissions, which drive climate change. Growing concerns over this issue have led to global agreements aimed at reducing emissions and limiting the rise in global temperatures to below 2°C. One strategic solution to achieve Net Zero Emissions (NZE) in the transportation sector is the development of vehicles powered by environmentally friendly energy sources [1]. Among these alternatives, electric vehicles (EV) powered by batteries are currently the most rapidly advancing. However, the EV industry still faces challenges, particularly in ensuring battery safety, extending driving range, and reducing costs [2]. Lithium-ion (Li-ion) batteries, while widely used, have limitations, especially in terms of thermal stability, which can lead to safety risks such as spontaneous combustion [3]. Therefore, it is necessary to develop new batteries to overcome these problems so that they can be used safely.

To address these issues, BYD, a Chinese battery manufacturer, introduced a new design known as the blade battery. In an acupuncture test conducted by Yu (2022), conventional block-type LFP (Lithium Iron Phosphate) batteries showed surface temperatures of 200–400°C with smoke generation, while blade-type LFP batteries remained between 30–60°C without smoke, indicating greater resistance to thermal runaway and better thermal stability [4]. This demonstrates that LFP has good safety and thermal stability, rendering it resistant to thermal runaway. Despite this advantage, LFP batteries still suffer from lower energy density and electronic conductivity compared to NMC (Nickel Manganese Cobalt) batteries [5]. To overcome this drawback, Zhang et al. incorporated manganese into LFP to form Lithium Manganese Iron Phosphate (LMFP). Their study found that the addition of 0.6 mol Mn significantly improved the electrochemical performance of the battery [6].

Effective battery thermal management is also essential in ensuring safety, reliability, and lifespan [7]. Sudden temperature fluctuations can lead to degradation, reduced efficiency, and even thermal runaway [8]. Integrating cooling systems is a practical solution to regulate battery temperature and mitigate thermal risks [9] This study investigates the thermal performance of blade-shaped LMFP batteries using a liquid cooling system. By combining the inherent safety of the blade form factor with the enhanced energy density from manganese addition, this research addresses current limitations in battery design, particularly in thermal behavior under high load. The study contributes by providing a thermal model that evaluates the battery's behavior under various operating conditions, offering practical insights for safer and more efficient EV battery system design [10].

2. Literature Review

To prevent climate change by reducing carbon emissions, Battery Electric vehicles (BEV) are increasingly in demand, making the development of battery technology crucial. The performance of an EV battery pack is influenced by various elements, with its vulnerability to heat effects being the primary concern [11]. The benefits of BEV technology include reduced electricity costs, zero emissions, and increased efficiency. The main parameters in batteries are energy density, power density, cycle life, and safety. Batteries play an important role because the amount of energy in the battery is directly proportional to the battery capacity. Lithium-ion batteries are the most suitable batteries for BEV technology because they have high energy density and power density [1]. Lithium-ion batteries are widely used in portable electronics, electric vehicles, and energy storage because they have a long life cycle, high energy density, and cost-effectiveness [8]. Lithium-ion batteries have an anode and a cathode. The cathode and anode serve as the load carriers for the energy storage and discharge of the battery. The cathode in a lithium-ion battery determines the energy density and thermal stability [12]. The main source of active lithium ions in batteries is the positive electrode material or cathode [13]. The types of Lithium-ion battery cathodes commonly used commercially in electric vehicles are Lithium-Manganese-Oxide (LMO), Lithium-Nickel-Manganese-Cobalt (NMC), and Lithium-Iron-Phosphate (LFP) [5]. Compared to NMC batteries, LFP batteries are known for their improved safety, mainly because of their remarkable thermal stability and resistance to thermal runaway, which reduces their risk of fire or explosion. Although NMC batteries have a greater nominal voltage, they need more stringent safety precautions since they are more prone to rapid thermal runaway [14]. LFP batteries are more environmentally friendly because they have less impact on the environment during the production stage. After all, there is no nickel and cobalt [15].

LFP batteries have disadvantages such as low-rate capability, which reduces the electronic conductivity performance and the rate of lithium-ion diffusion coefficient. The addition of metal ions and related structural engineering techniques offer beneficial methods for surpassing conventional constraints in battery electrodes, leading to enhanced energy density and operational efficiency [16]. Zhang et al. studied the addition of manganese to LFP batteries with a composition of LiMn0.6Fe0.4PO4 and found that the discharge capacity and energy density could be maintained at 152 mAh/g and 570 Wh/kg at a discharge rate of 0.1C. The effect of high electronic conductivity significantly accelerated the diffusion of lithium ions, resulting in improved capacity and performance of the material. [6]. In this study, a lithium iron phosphate battery will be used with the addition of manganese elements.

Blade batteries can be incorporated into the battery pack system due to their long and thin cells. Blade batteries increase volumetric power density and drastically lower costs by improving battery packaging efficiency through the application of the Cell-to-Pack concept [8]. Blade batteries have a blade-like and thin shape, which allows for better thermal management and reduces the risk of thermal runaway [17]. The shape of the blade cell can be seen in Figure 1.

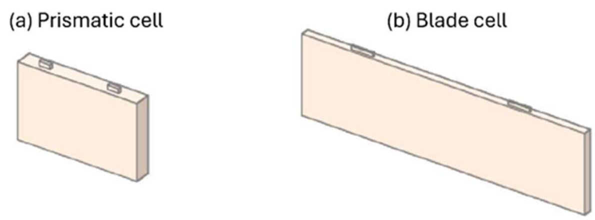

Figure 1. Comparison of Battery Cell Shapes [10]

The blade battery design can enhance preheating and cooling effectiveness. The blade battery's Battery Management System (BMS) is made to optimize battery management, shorten low-temperature heating times, and extend the remaining service life. Battery performance and safety are maintained by battery management systems [18]. During charging and discharging, batteries generate significant heat and can reduce efficiency and safety risks. Therefore, an effective battery thermal management system (BTMS) is required to ensure optimal battery operation [19]. In battery design, thermal analysis is used to examine real-world occurrences, particularly for battery safety simulation. Temperature is a crucial element that can shorten battery life, reduce performance, and raise safety concerns. Thermal analysis can evaluate battery temperature predictions by estimating heat generation in the battery during the charge and discharge phases [20]. Thermal management systems can effectively cope with extreme operating conditions. They can maintain operating temperatures within the desired range set by the battery manufacturer and minimize temperature differences across battery cells in a module [7]. Li-ion batteries show the best operating performance in the temperature range of 15–35°C. At lower temperatures, the ability of lithium ions to diffuse is limited and increases the internal impedance and the discharge capacity of the battery decreases [21]. One of the battery thermal management systems approaches for battery operating temperature that is widely used is the cooling system. Cooling systems have two types that are commonly used, liquid-cooling systems and air-cooling systems [9]. To determine the effective thermal distribution, the cooling system is incorporated into the thermal analysis.

Water cooling is typically more efficient than air cooling for regulating the heat generated by Li-ion batteries, especially due to water's greater heat capacity and thermal conductivity, enabling it to absorb and dissipate heat more effectively at reduced flow rates [22]. A liquid cooling system provides better temperature uniformity across the battery area. This uniformity is important to prevent hotspots and ensure battery longevity and safety [23]. Ren et al. studied the temperature changes of the cooling system in the battery and found that the battery temperature can be maintained at a temperature below 45°C by lowering the temperature of the cooling system [24]. Battery cooling can be analyzed using tools such as Computer-Aided Engineering (CAE) by creating 3D designs through Computer-Aided Design (CAD) to investigate the thermal distribution of each cell. To analyze the thermals related to battery operating conditions, CAE was used with a Computational Fluid Dynamic (CFD) approach [20]. To simplify the calculation, the thermal modeling does not consider the inner geometric structure of the battery. Simplified geometry models that typically solely represent the battery's exterior are frequently used in computational fluid dynamics (CFD) simulations of batteries in order to lower computational complexity and expedite computations [25].

To forecast the thermal performance, thermal modeling of Li-ion batteries is carried out using mathematical formulas depending on temperature circumstances. These equations are developed using established energy, electrochemistry, heat generation, and transfer equations with the constraints of the working environment. Methods such as CFD are essential for assessing the thermal characteristics of Li-ion batteries [26]. Battery thermal is solved in the CFD domain at the single-cell battery scale using the following differential equations [27]:

$$\frac{\partial \rho C_p T}{\partial t} - \nabla.(k\nabla \mathrm{T}) = \mathrm{q} \tag{1}$$

Particularly at high discharge rates or in unfavorable climatic circumstances, effective cooling systems help keep battery temperatures within optimum ranges, lowering the possibility of thermal runaway, increasing temperature uniformity, and increasing cycle life and performance [28]. In this study, ANSYS software will be used to investigate the temperature distribution in battery cells.

3. Methodology

The modeling began with 3D geometry design of the blade battery using ANSYS Space Claim. In conducting simulations, battery cells were modeled as active zones, while tab nodes (negative and positive) served as passive zones [27]. The simulation procedure is systematically outlined in the following steps, encompassing the geometric modeling, meshing, boundary condition setup, and post-processing stages.

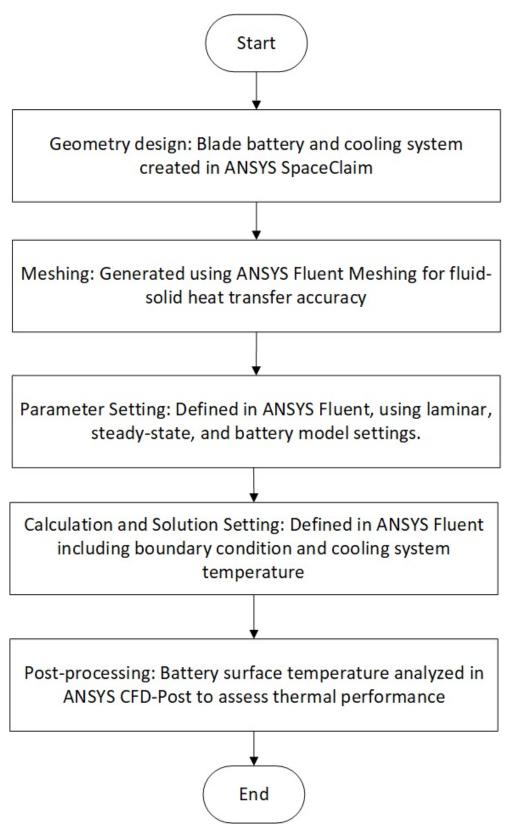

Figure 2. Simulation Flowchart

The blade battery was dimensioned at 960 mm (length) × 90 mm (height) × 13.5 mm (thickness) [29]. The cooling system was integrated directly with the battery cell following a cell-level cooling design. The cooling plate geometry was modeled with a thickness of 3 mm, 10 mm channel width, and 5 cooling channels. A simplified battery model was adopted to reduce computational load while preserving the essential heat transfer characteristics of the system. This simplified modeling is justified by prior studies that found minimal deviation in thermal behavior using similar geometric abstraction [21]. The 3D geometry of the battery can be seen in Figure 3.

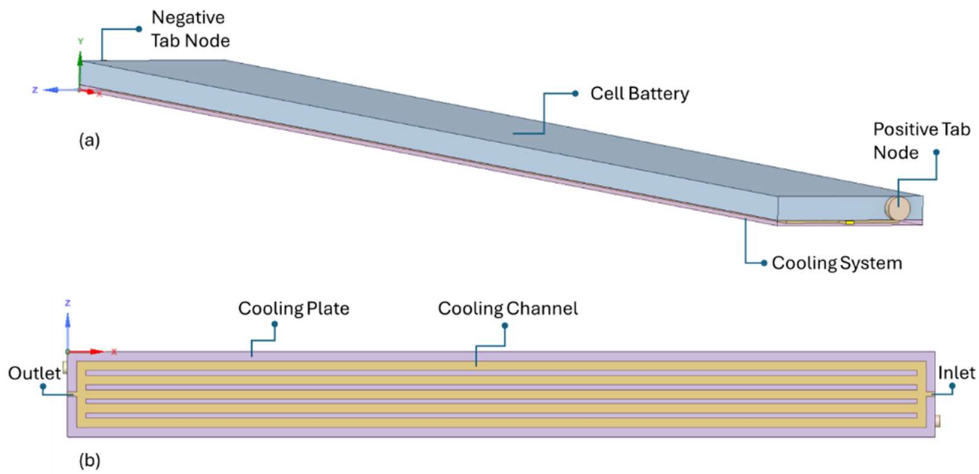

Figure 3. 3D Geometry Design of Blade Battery

After geometry was designed, the meshing process was carried out in ANSYS Fluent Meshing to generate a computational grid suitable for fluid-solid heat transfer interaction. During the processing phase, simulation parameters and boundary conditions were defined in ANSYS Fluent. Steady-state laminar flow was assumed with water coolant entering at 0.5 m/s. The heat transfer coefficient at the solid-liquid interface was set at 5 W/m²·K, consistent with similar battery cooling studies to ensure realistic thermal interaction at the wall boundaries [30]. Material Properties of the battery, aluminum plate, and water can be seen in Table 1.

Table 1. Material Properties of Battery, Aluminum Plate, and Water

Material	$\boldsymbol{Density}$ $(\boldsymbol{kg\ m^{-3}})$	$\boldsymbol{Specific\ Heat}$ $(\boldsymbol{J\ Kg^{-1}k^{-1}})$	$\boldsymbol{Conductivity}$ $(\boldsymbol{W\ m^{-1}k^{-1}})$
Aluminum	2719	871	202.4
Water	998.2	4128	0.6
LMFP Battery	2590	850	2

The simulation adopted the Multi-Scale Multi-Domain (MSMD) approach as the solution method and used the NTGK/DCIR electrochemical model to approximate battery heat generation behavior under various C-rates and cooling conditions. The temperature of the coolant inlet was varied at 14.85°C, 26.85°C, and 34.85°C, while discharge rates (C-rates) of 0.5C, 1C, 2C, and 5C were simulated to assess the thermal behavior under different load conditions. The post-processing stage was conducted using ANSYS CFD-Post, where the resulting temperature distributions were visualized via contour plots. The analysis enabled a detailed evaluation of heat propagation within the battery and the cooling system's effectiveness in maintaining battery temperature within the optimal range. The C-rates and cooling temperatures were selected to represent common EV operation under low to high load, based on prior empirical studies.

4. Finding and Discussion

4.1. Effect of C-Rate on Thermal Performance

The variation of battery temperature at different C-rates (0.5C, 1C, 2C, and 5C), all under the same cooling condition with an inlet coolant temperature of 300 K. The effects of C-rates on thermal performance are shown in Figure. 4.

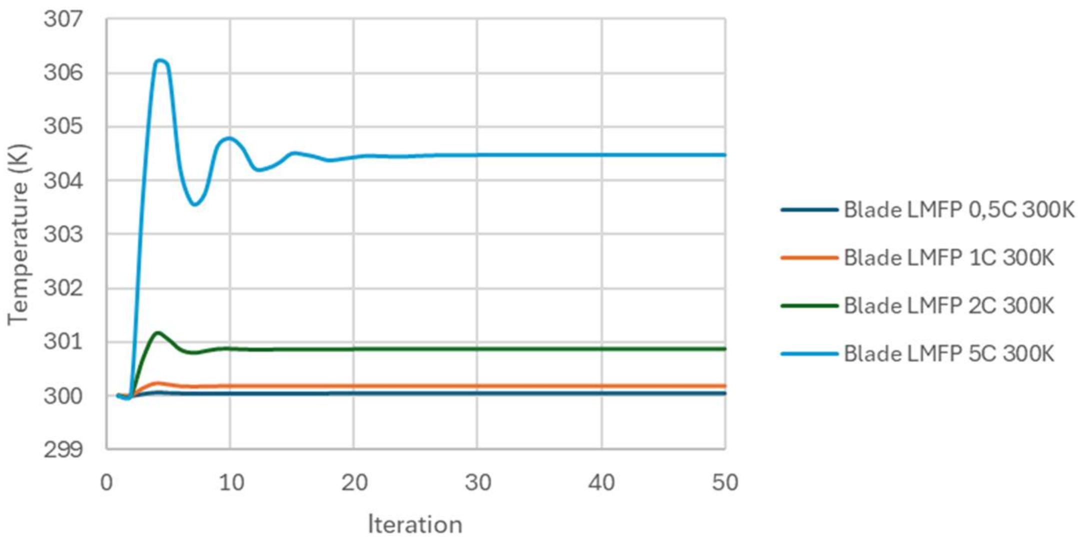

Figure 4. Effect of C-Rate on Thermal Performance

The results indicate that increasing the C-rate leads to a significant rise in battery temperature. At 0.5C, minimal internal heat generation leads to a uniform temperature distribution of around 301 K, which is effectively handled by the cooling system. As the C-rate increases to 1C and 2C, the peak temperature rises gradually to 302 K and 303.5 K. At 5C, the battery experiences a sharp increase in temperature, stabilizing at around 305 K. This aligns with the expected behavior, as the internal heat generation is proportional to current and internal resistance, according to the NTGK/DCIR heat source model.

Figure 5. Heat Distribution from Effect of C-Rate on Thermal Performance for Battery with Inlet Cooling System 300K and C-rate 0.5C

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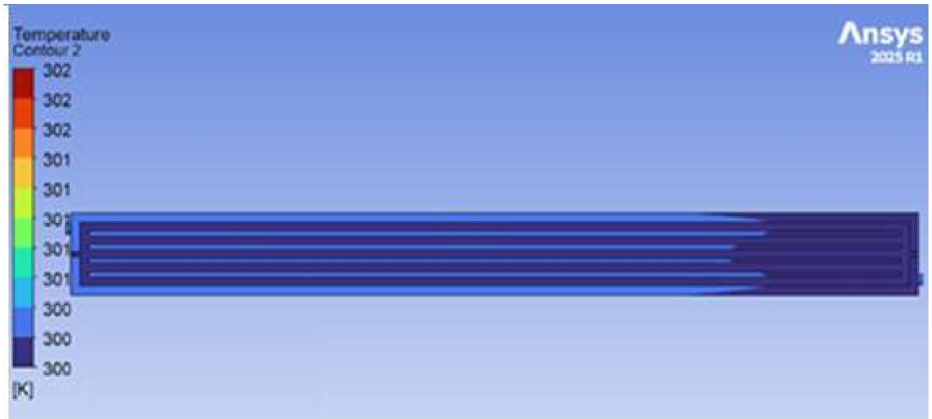

Figure 6. Heat Distribution from Effect of C-Rate on Thermal Performance for Battery with Inlet Cooling System 300K and C-rate 1C

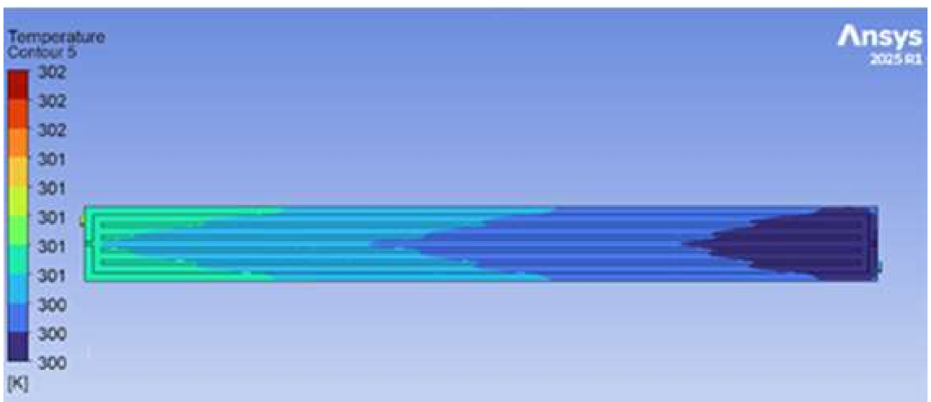

Figure 7. Heat Distribution from Effect of C-Rate on Thermal Performance for Battery with Inlet Cooling System 300K and C-rate 2C

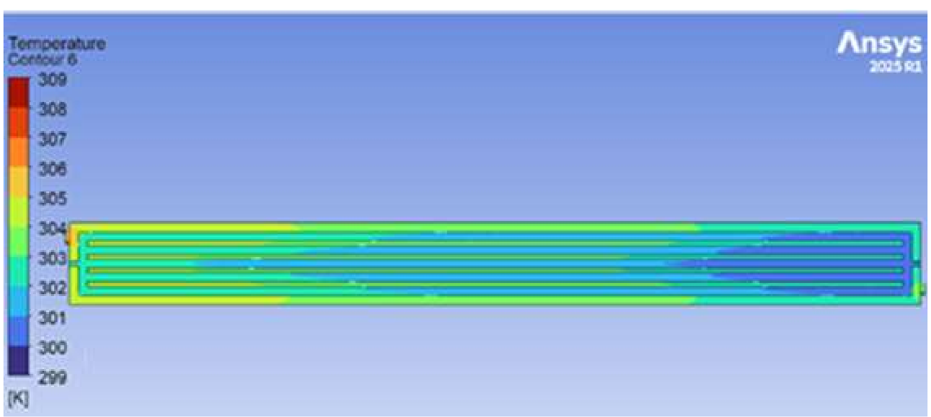

Figure 8. Heat Distribution from Effect of C-Rate on Thermal Performance for Battery with Inlet Cooling System 300K and C-rate 5C.

As the C-rate increases, the temperature distribution within the battery becomes significantly higher and more non-uniform. This is primarily due to the elevated internal heat generation associated with higher charge and discharge rates. At low C-rates, the battery generates minimal heat, allowing the cooling system to maintain a relatively uniform and low temperature throughout the cell. However, as the C-rate rises, the rate of electrochemical reactions accelerates, leading to increased thermal energy that is more difficult to dissipate effectively [28]. This results in higher peak temperatures and greater thermal gradients within the battery. The contour plots from the heat distribution of the batteries are shown in Figure 5, Figure 6, Figure 7 and Figure 8.

As shown in Figure 5, Figure 6, Figure 7 and Figure 8, increasing the C-rate from 0.5C to 5C results in a progressive rise in peak temperature and greater non-uniformity in heat distribution. While the cooling system maintains stability at low C-rates, its efficiency diminishes at higher loads, evident from the thermal gradient forming from inlet to outlet. At 5C, the system reaches thermal limits, suggesting the need for enhanced cooling strategies in high-power scenarios. The non-uniformity is visible, with a significant gradient from inlet to outlet, especially across the flow channels. This reflects the intense internal heat generation at a high current, which challenges the thermal control capacity of the cooling system. This highlights the importance of optimized thermal management for high-power applications, where insufficient cooling can lead to thermal stress and potential safety risks.

4.2. Effect of Cooling System Temperature on Thermal Performance

The thermal behavior of LMFP blade cells at different cooling system temperatures (308 K, 300 K, and 288 K) and C-rates (1C and 5C). The effects of the cooling system on thermal performance are shown in Figure 9.

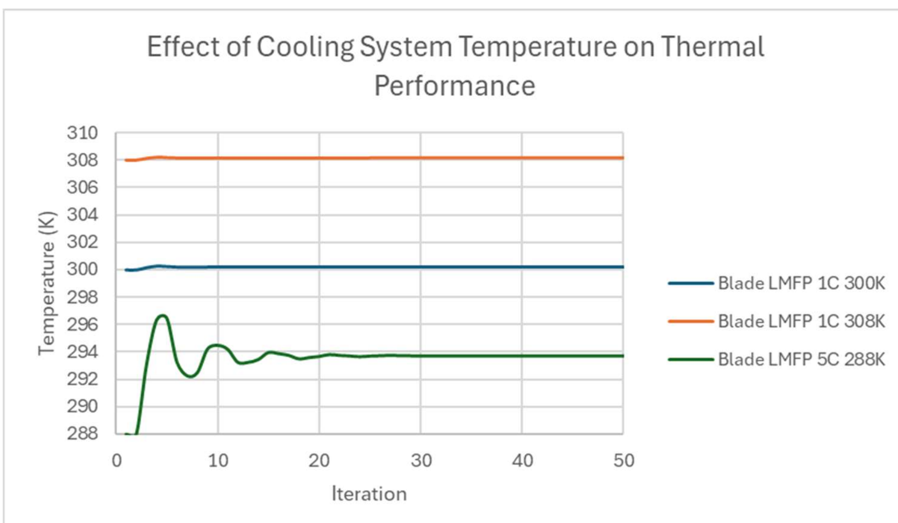

Figure 9. Effect of Cooling System Temperature on Thermal Performance

The results highlight the impact of coolant inlet temperature on maintaining battery temperature under varying operating loads. At 1C with a coolant of 300 K, the battery temperature stabilizes around 301.5 K, with minimal fluctuation. Lowering the coolant temperature to 288 K for the 5C case dramatically improves thermal control, with the battery temperature stabilizing at 295 K. Lower coolant inlet temperature improves heat dissipation efficiency, particularly at elevated C rates [31]. Raising the inlet coolant temperature to 308 K under the same C-rate (1C) resulted in a substantial rise in battery temperature. The contour plots from the heat distribution of the batteries are shown in Figure 7.

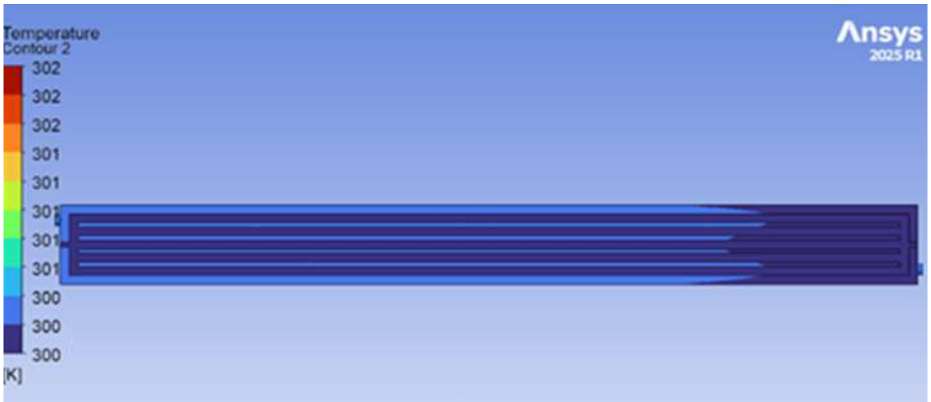

Figure 10. Heat Distribution from Different Cooling System Temperature on Thermal Performance: Battery with inlet Cooling System 300 K and C-rate 1C

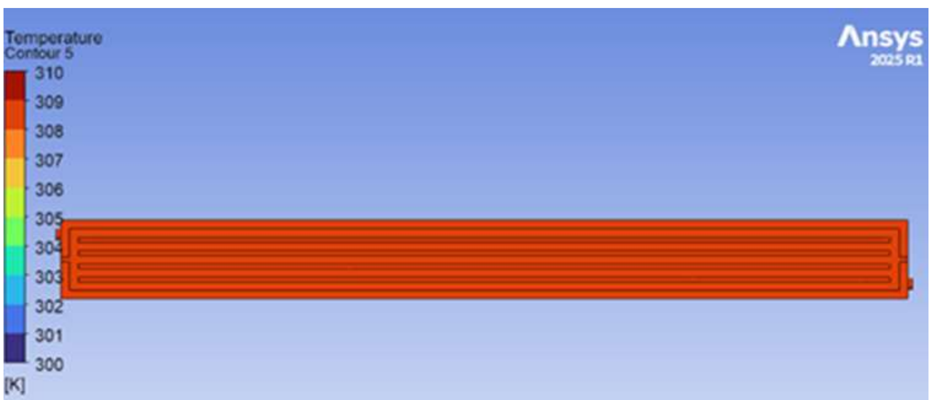

Figure 11. Heat Distribution from Different Cooling System Temperature on Thermal Performance: Battery with inlet cooling system 308K and C-rate 1C

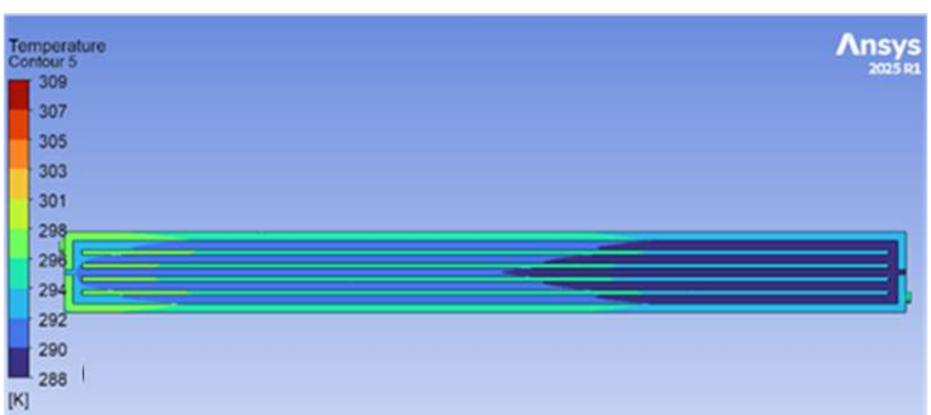

Figure 12. Heat Distribution from Different Cooling System Temperature on Thermal Performance: Battery with inlet cooling system 288K and C-rate 5C

Figure 10, Figure 11 and Figure 12 presents the heat distribution of the battery under different coolant inlet temperatures. The results clearly demonstrate the influence of coolant temperature on thermal management effectiveness. At moderate C-rate (1C) with a standard coolant temperature of 300 K (Figure 10), the battery temperature remains relatively uniform (300–301.5 K), with minor increases near the outlet region. This signifies consistent thermal performance under typical operating conditions. When the coolant temperature is increased to 308 K (Figure 11), the system's ability to absorb heat is significantly reduced. The battery experiences a more uniform yet elevated temperature exceeding 304 K, suggesting thermal accumulation and reduced cooling efficiency. Such conditions can accelerate battery degradation and shorten lifespan. In contrast, applying a lower coolant temperature of 288 K at a high C-rate of 5C (Figure 12) proves to be highly effective. Despite the greater thermal load, the temperature remains within a controlled range (293–298 K), showing that a colder coolant substantially enhances heat dissipation and prevents excessive temperature rise. The results suggest that lowering the coolant temperature is an effective strategy to manage thermal load in high C-rate operations, which is critical for battery longevity and thermal safety in EV applications.

5. Conclusion

This study demonstrated that both C-rate and coolant inlet temperature significantly affect the thermal performance of blade-type LMFP batteries equipped with a liquid cooling system. Based on the analysis conducted, it is evident that inlet coolant temperature plays a critical role in determining the thermal performance of blade-type LMFP batteries. At a moderate C-rate of 1C, a coolant temperature of 300 K enables effective heat dissipation, maintaining a stable and safe temperature distribution within the battery pack. However, when the inlet temperature is increased to 308 K under the same C-rate, the cooling effectiveness is significantly reduced, resulting in a uniformly high-temperature field that may accelerate battery degradation despite the moderate heat generation. At a high C-rate of 5C, the implementation of a lower inlet temperature of 288 K successfully counteracts the intensified heat load, maintaining the cell temperature below critical thresholds and demonstrating the benefits of enhanced thermal absorption. These findings highlight the non-linear relationship between C-rate and coolant temperature, emphasizing that higher inlet temperatures can be detrimental to battery longevity, even under standard operating conditions. Therefore, precise control of the coolant inlet temperature is essential in designing an efficient Battery Thermal Management System, particularly for applications with variable ambient conditions and dynamic load profiles such as electric vehicles. This work was confined to steady-state simulations and ideal boundary conditions, which may not fully capture transient thermal responses. Future research is recommended to explore the integration of adaptive cooling control strategies, such as variable flow rate or number of cooling channels, to dynamically respond to real-time temperature variations. In addition, testing under cyclic charge-discharge conditions and varied ambient environments would provide a more comprehensive understanding of battery behavior in actual EV usage.

References

[1] N. Tiwari *et al.*, “Converting gasoline vehicle into an electric vehicle (EV)-A review,” *Mater Today Proc*, vol. 79, pp. 379–388, 2023.
[2] H. Roy *et al.*, “Global Advancements and Current Challenges of Electric Vehicle Batteries and Their Prospects: A Comprehensive Review,” *Sustainability (Switzerland)*, vol. 14, no. 24, 2022.
[3] S. Hasan *et al.*, “Beyond Lithium-Ion: The Promise and Pitfalls of BYD’s Blade Batteries for Electric Vehicles,” *E3S Web of Conferences*, vol. 469, 2023.
[4] G. Yu, “The Analysis on the Principle and Advantages of Blade Battery of BYD -- A Domestic New Energy Manufacturer,” *SHS Web of Conferences*, vol. 144, p. 02003, 2022.
[5] M. Sen, “A review on the lithium-ion battery problems used in electric vehicles,” vol. 3, no. October 2023, 2024.
[6] B. Zhang *et al.*, “High-energy–density lithium manganese iron phosphate for lithium-ion batteries: Progresses, challenges, and prospects,” *Journal of Energy Chemistry*, vol. 100, pp. 1–17, 2025.
[7] G. Zhao, X. Wang, M. Negnevitsky, and C. Li, “An up-to-date review on the design improvement and optimization of the liquid-cooling battery thermal management system for electric vehicles,” *Appl Therm Eng*, vol. 219, no. July 2022, 2023.

[8] X. Feng, F. Zhang, W. Huang, Y. Peng, C. Xu, and M. Ouyang, "Mechanism of internal thermal runaway propagation in blade batteries," *Journal of Energy Chemistry*, vol. 89, pp. 184–194, 2024, doi: 10.1016/j.jechem.2023.09.050.
[9] A. Sadar, M. Amir, and N. Mohammad, "An optimal design of battery thermal management system with advanced heating and cooling control mechanism for lithium-ion storage packs in electric vehicles," *J Energy Storage*, vol. 99, Oct. 2024, doi: 10.1016/j.est.2024.113421.
[10] X. Yang, T. Liu, and C. Wang, "Thermally modulated lithium iron phosphate batteries for mass-market electric vehicles," *Nat Energy*, 2021.
[11] F. S. Hwang *et al.*, "Review of battery thermal management systems in electric vehicles," *Renewable and Sustainable Energy Reviews*, vol. 192, no. December 2023, 2024.
[12] Y. Lv *et al.*, "Review on influence factors and prevention control technologies of lithium-ion battery energy storage safety," *J Energy Storage*, vol. 72, no. April, 2023.
[13] V. Singh, S. Kuthe, and N. V. Skorodumova, "Electrode Fabrication Techniques for Li Ion Based Energy Storage System: A Review," *Batteries*, vol. 9, no. 3, 2023.
[14] J. Schöberl, M. Ank, M. Schreiber, N. Wassiliadis, and M. Lienkamp, "Thermal runaway propagation in automotive lithium-ion batteries with NMC-811 and LFP cathodes: Safety requirements and impact on system integration," *eTransportation*, vol. 19, no. December 2023.
[15] X. Shu, Y. Guo, W. Yang, K. Wei, and G. Zhu, "Life-cycle assessment of the environmental impact of the batteries used in pure electric passenger cars," *Energy Reports*, vol. 7, no. November, pp. 2302–2315, 2021.
[16] M. Yang *et al.*, "Enhancing control over organic cathodes through metal coordination for efficient lithium/sodium ion batteries," *Nano Energy*, vol. 129, no. December 2023, 2024.
[17] R. Bin Hossain, S. Mohammad, N. Sakib, S. Islam, P. Roy, and S. Hasan, "A Comprehensive Review of Blade Battery Technology for the Vehicle Industry," *North American Academic Research*, vol. 6, no. 6, pp. 1–20, 2023.
[18] S. Mishra, S. C. Swain, and R. K. Samantaray, "A Review on Battery Management system and its Application in Electric vehicle," *10th International Conference on Advances in Computing and Communications, ICACC 2021*, 2021.
[19] C. Y. Guo, M. W. Muhieldeen, K. H. Teng, C. K. Ang, and W. H. Lim, "A novel thermal management system for lithium-ion battery modules combining indirect liquid-cooling with forced air-cooling: Deep learning approach," *J Energy Storage*, vol. 94, no. June, 2024.
[20] P. Cicconi and P. Kumar, "Design approaches for Li-ion battery packs: A review," *J Energy Storage*, vol. 73, no. August, 2023.
[21] J. Liu, H. Chen, S. Huang, Y. Jiao, and M. Chen, "Recent Progress and Prospects in Liquid Cooling Thermal Management System for Lithium-Ion Batteries," *Batteries*, vol. 9, no. 8, 2023.
[22] B. Heidarshenas, A. Aghaei, A. Hossein Zamani, and Y. Yuan, "Comparison of different cooling techniques for a lithium-ion battery at various discharge rates using electrochemical thermal modeling," *Appl Therm Eng*, vol. 258, no. November 2024.
[23] N. Zhang *et al.*, "Performance investigation of battery thermal management system based on L-shaped heat pipe coupled cold plate and optimization of controllable liquid cooling," *Engineering Applications of Computational Fluid Mechanics*, vol. 18, no. 1, 2024.
[24] R. Ren, Y. Zhao, Y. Diao, and L. Liang, "Experimental study on the bottom liquid cooling thermal management system for lithium-ion battery based on multichannel flat tube," *Appl Therm Eng*, vol. 219, no. 100, 2023.
[25] Y. Jiang, L. Zhang, G. Offer, and H. Wang, "A user-friendly lithium battery simulator based on open-source CFD," *Digital Chemical Engineering*, vol. 5, no. August, 2022.
[26] H. M. Ali, "Thermal management systems for batteries in electric vehicles: A recent review," *Energy Reports*, vol. 9, pp. 5545–5564, 2023.
[27] Inc. ANSYS, "CFD EXPERTS Simulate the Future," 2021.
[28] M. Li, S. Ma, H. Jin, R. Wang, and Y. Jiang, "Performance analysis of liquid cooling battery thermal management system in different cooling cases," *Journal of Energy Storage*, vol. 72, no. February, 2023.
[29] Y. Sun *et al.*, "Estimation of temperature field for blade battery based on frequency domain heat generation model," *International Journal of Heat Mass Transfer*, vol. 235, no. September, 2024.

[30] F. Chen, J. Wang, and X. Yang, "Topology optimization design and numerical analysis on cold plates for lithium-ion battery thermal management," *International Journal of Heat Mass Transfer*, vol. 183, 2022.

[31] Z. Qasmi, "ANSYS simulation of Temperature of Cooling System in Li-ion Battery," pp. 44–450, 2022