

Research on the influence of heat sink plate structural parameters on the cooling efficiency of electric vehicle battery packs

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ABSTRACT: In the global trend toward green and sustainable energy, the electric vehicle (EV) industry has experienced rapid growth, with energy storage emerging as one of the primary challenges for manufacturers and researchers. Lithium-ion batteries are currently the dominant technology used in EVs due to their high energy density and excellent cycle stability; however, their performance is highly sensitive to operating temperature. To ensure optimal operation, battery packs must be maintained within a controlled temperature range of 15°C to 35°C. Elevated temperatures accelerate parasitic reactions, including oxidation and electrolyte degradation, which lead to performance deterioration and may pose serious safety risks such as thermal runaway, fire, or explosion. Consequently, the development of an efficient and reliable battery thermal management system (BTMS) is essential to enhance heat dissipation and maintain temperature uniformity within the battery pack. Current research on thermal optimization focuses on key design parameters, such as channel thickness, wall thickness, and curvature angle, and their effects on the maximum temperature and temperature distribution among cells.

KEYWORDS: Cooling performance; Lithium-ion battery module; Air cooling strategies; ANSYS Fluent

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I. INTRODUCTION

Amid the accelerated evolution of electric vehicle (EV) technologies, battery thermal management has become a critical factor influencing both performance and lifespan. The battery thermal management system (BTMS) serves a critical function in maintaining the battery within an optimal temperature range while ensuring temperature uniformity among individual cells and modules. Elevated temperatures accelerate parasitic side reactions within the battery, leading to performance degradation, reduced lifespan, and potentially triggering thermal runaway. Conversely, low temperatures increase internal resistance and reduce capacity, thereby diminishing overall battery performance [3]. Therefore, the development of an appropriate BTMS is essential to achieve optimal performance of battery energy storage systems. Various BTMS technologies have been proposed, including air cooling (AC), liquid cooling (LC), refrigerant direct cooling (RDC), phase change material (PCM)-based cooling, thermoelectric cooling (TC), heat pipe cooling (HPC), and hybrid cooling systems (HC) [4]. Among these approaches, liquid cooling has emerged as a leading solution for mitigating thermal risks in battery packs, as it provides effective temperature regulation under diverse operating conditions and significantly outperforms air cooling methods [5]. Recent studies have focused on improving BTMS performance. Basu et al. [6] developed a compact and cost-effective BTMS for 18650 battery packs, integrating an electrochemical-thermal coupled model to evaluate the impact of operating conditions on battery temperature. Their findings highlighted the critical role of contact resistance between battery cells and the cooling plate in determining thermal performance. Wang et al. [7] investigated a modular BTMS and examined the effects of coolant velocity and flow direction on 18650 battery packs. The results indicated that increasing coolant velocity within a certain range enhances cooling performance and temperature uniformity, with parallel flow configurations outperforming series arrangements. Furthermore, studies by S. Wiriyasart et al. and Gaurav Raj Pandey [8,9] developed experimental models demonstrating that the use of nanofluids instead of conventional coolants can significantly enhance heat transfer efficiency while reducing energy consumption through improved flow control and lower operating temperatures. In addition, several advanced heat sink structures have been proposed to further improve BTMS performance. Lai et al. [10] introduced a microchannel-based BTMS employing the Tesla valve principle, demonstrating superior cooling efficiency and flow dynamics compared to conventional straight microchannel systems.

Based on these findings, investigating the influence of heat sink structural parameters on the cooling performance of EV battery packs is both necessary and scientifically meaningful. Such research can further enhance thermal performance while minimizing adverse thermal effects, thereby contributing to the

sustainable and efficient development of the electric vehicle industry.

II. COMPUTATIONAL DOMAIN AND GOVERNING EQUATIONS

This study evaluates the influence of heat sink structural parameters on the thermal performance of electric vehicle battery packs. A battery pack model consisting of four rows of 18650 cells was developed, each row containing 19 cells. A waveform heat sink configuration was used, as illustrated in Figure 1a. The battery thermos-physical parameters are shown in Table 1

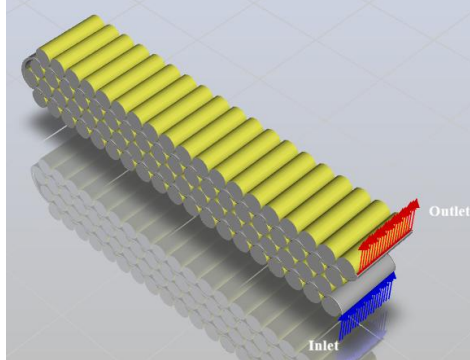


Figure 1a Battery pack model

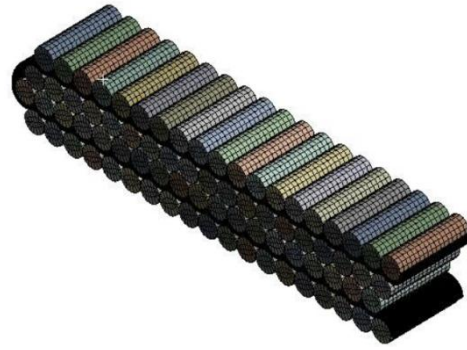


Figure 1b Close-up of mesh elements of battery pack

Table 1: The battery thermos-physical parameters

Parameter	Value	Unit
Rated Voltage	3.6	V
Specific Heat Capacity	1200	J·kg ⁻¹ ·K ⁻¹
Density	2722	kg·m ⁻³
Length	65	mm
Diameter	18	mm
Radial Thermal Conductivity (kr)	0.2	W·m ⁻¹ ·K ⁻¹
Axial Thermal Conductivity (kz)	37.6	W·m ⁻¹ ·K ⁻¹

The Multizone meshing method was chosen to subdivide the computational domain (Figure 1b). This is a meshing technique that combines hexahedron and tetrahedron elements to optimize accuracy and computational performance. The mesh size is approximately 1 to 2 million mesh elements and has about 3 million nodes.

In ANSYS-Fluent, the governing equations include the continuity, momentum, and energy equations. For the cooling air, these equations are shown as:

Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho u) = 0 \quad (1)$$

Momentum equation:

$$\rho \frac{\partial u}{\partial t} + \rho u \cdot \nabla u = -\nabla p + \eta \nabla^2 u \quad (2)$$

Energy equation:

$$\frac{\partial(\rho c_p T)}{\partial t} + \nabla(\rho c_p u T) = \nabla(k \nabla T) \quad (3)$$

For the battery cell, the energy governing equation is expressed by:

$$\rho c_p \frac{\partial T}{\partial t} = \nabla(k \nabla T) + q \quad (4)$$

where ρ , c_p , T , p , k , and q denote the density, specific heat, temperature, pressure, heat conductivity coefficient, and the heat generation rate per unit volume of the battery, respectively.

A battery is considered as a uniform heat source. The heat generation rate per unit volume is expressed as equation 5.

$$q = a_0 + a_1t + a_2t^2 + \dots + a_nt^n \quad (5)$$

Where $a_0 \sim a_n$ are coefficients corresponding to the polynomial fitting method, $q(\text{W/m}^3)$ is the heat generation rate and $t(\text{sec})$ is the time passed. These values were taken from [11]. The heat generation model is defined as an energy source term incorporated into CFD simulation using a user-defined function (UDF).

The standard k - ϵ model is selected which has been widely validated in modeling general low-speed and low-pressure flow around obstacles [12]. The k - ϵ turbulence model includes two equations for the turbulent kinetic energy k and the turbulent kinetic energy dissipation rate ϵ .

Turbulent kinetic energy equation:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu t}{\alpha k} \right) \frac{\partial k}{\partial x_j} \right) + Gk + Gb - \rho \epsilon - YM + Sk \quad (6)$$

Turbulent kinetic energy dissipation equation:

$$\frac{\partial}{\partial t}(\rho \epsilon) + \frac{\partial}{\partial x_j}(\rho \epsilon u_j) = \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu t}{\alpha \epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right) + C1 \epsilon \frac{\epsilon}{k} (Gk + C3 \epsilon Gb) - \rho C2 \epsilon \frac{\epsilon^2}{k} + S\epsilon \quad (7)$$

where k and ϵ denote turbulent kinetic energy and turbulent dissipation rate, respectively.

The settings for the boundary conditions are as follows. The inlet and outlet are set as the velocity inlet and the pressure outlet, respectively. The top and bottom are defined as walls. Also, side one and side two are defined as walls as well. In addition, the interfaces between batteries and fluid are defined as coupled walls.

The convergence criterion, i.e., the scaled residual, for both mass, momentum and energy equations are set to 10^{-5} and 10^{-6} , respectively, in each time step of the flow.

III. RESULTS AND DISCUSSION

Maximum temperature (T_{max}) and maximum temperature difference (ΔT_{max}) are important parameters for evaluating the performance of a battery thermal management system (BTMS). ΔT_{max} represents the highest temperature difference observed between batteries and serves as a key indicator of the system's effectiveness in regulating and controlling battery temperature. Therefore, to examine the influence of heat sink structural parameters on battery cooling efficiency, this study evaluates the performance by varying the channel thickness and fillet angle (the angle at which the heat sink wraps around the battery). The research results are shown in Figures 2a and 2b.

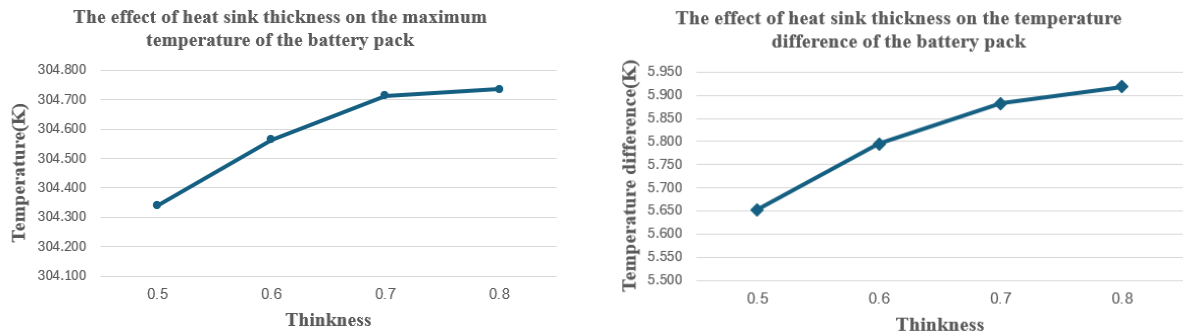


Figure 2a The effect of heat sink thickness on the maximum temperature and temperature difference of the battery pack

Figure 2, as the cooling plate wall thickness increases from 0.5 to 0.8, both the maximum temperature (T_{max}) and the temperature difference between cells (ΔT) show a consistent increasing trend, while the rate of increase gradually diminishes. Specifically, T_{max} rises from 304.339°K to 304.735°K , corresponding to a total increase of 0.396°K (approximately 0.13%). However, the incremental growth decreases significantly across intervals, from 0.0736% to only 0.0069%, indicating a saturation behavior in which further increases in wall thickness provide negligible thermal improvement. In contrast, the temperature non-uniformity ΔT increases from 5.653°K to 5.918°K , equivalent to a total rise of 0.265°K (about 4.69%), which is more pronounced than that observed for T_{max} . The relative increase also declines progressively 2.51% - 1.50% - 0.61% suggesting that although a thicker cooling plate wall continues to degrade thermal uniformity, its marginal impact becomes weaker at higher thickness values. From a physical standpoint, increasing the cooling plate wall thickness enhances the thermal conduction path between the coolant and the battery cells, effectively increasing thermal resistance. As a result, heat dissipation becomes less efficient, leading to a slight rise in T_{max} and a more noticeable increase in ΔT .

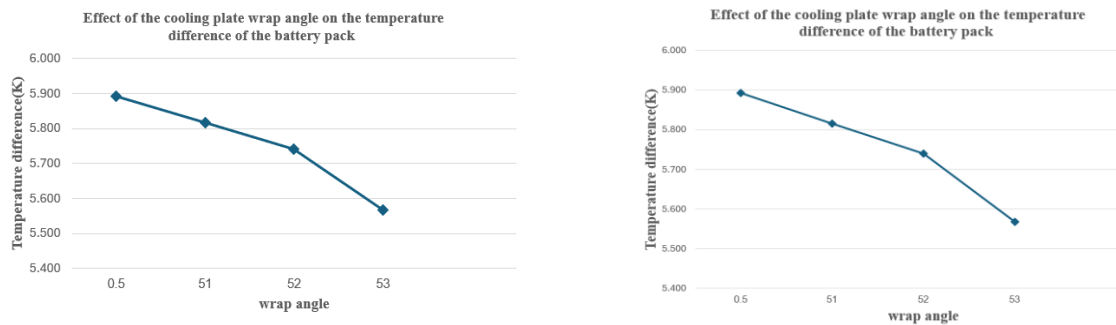


Figure 2b Effect of the cooling plate wrap angle on the maximum temperature and temperature difference of the battery pack

The results indicate that increasing the wrap angle from 51° to 54° leads to a reduction in both the maximum temperature (T_{max}) and the temperature difference (ΔT) of the battery pack. Specifically, T_{max} decreases from 304.728⁰K to 304.461⁰K, corresponding to a reduction of approximately 0.088%, while ΔT decreases from 5.892 ⁰K to 5.613⁰K, equivalent to a more significant reduction of about 4.73%. This trend demonstrates that although the influence of wrap angle on the peak temperature is relatively minor, its effect on improving temperature uniformity is more pronounced. Therefore, increasing the wrap angle contributes to enhanced thermal management performance, primarily by reducing temperature gradients within the battery pack, which is beneficial for improving battery durability and operational safety. However, increasing the wrap angle excessively does not always yield beneficial outcomes. As the wrap angle increases, the flow path length and the contact area between the coolant and the battery surface are enlarged, which enhances convective heat transfer and improves cooling performance. Nevertheless, this also leads to a significant rise in pressure drop and flow resistance, thereby increasing the required pumping or fan power and reducing the overall energy efficiency of the system. In addition, a larger wrap angle results in a more complex cooling plate geometry, which may introduce manufacturing challenges and lead to higher production costs.

IV. CONCLUSION

In summary, the structural parameters of the cooling plate significantly influence the thermal performance of the battery pack in an electric vehicle. Increasing the cooling plate wall thickness leads to a slight rise in maximum temperature and a more noticeable increase in temperature non-uniformity due to the higher thermal resistance, indicating a deterioration in cooling effectiveness beyond a certain threshold. In contrast, increasing the wrap angle improves thermal performance by reducing both T_{max} and ΔT , particularly enhancing temperature uniformity within the battery pack. However, excessive wrap angles may introduce higher pressure losses, increased energy consumption, and manufacturing complexity. Therefore, an optimal combination of relatively small wall thickness and moderate wrap angle is essential to achieve efficient heat dissipation, good temperature uniformity, and overall system performance.

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REFERENCES

- [1]. Tham Boi Chau, "Nghiên cứu quá trình trao đổi nhiệt trong module Pin Lithium 18650 sử dụng trên xe điện bằng phương pháp số". Tạp chí khoa học công nghệ Hàng Hải, số 79, 8/2024
- [2]. Nguyen Thanh Cong, Le Dinh Tan, Le Van Quynh, "Mô phỏng số cho gói pin Lithium ion sử dụng làm mát với hai cấu trúc tản nhiệt". Tạp chí cơ khí Việt Nam số đặc biệt tr. 432-434, tháng 11 năm 2024
- [3]. "Performance analysis of liquid cooling battery thermal management system in different cooling cases" Ming Li a b, Shiming Ma a b, Hui Jin c, Rujin Wang d, Yan Jiang a b Journal of Energy Storage Volume 72, Part D, 30 November 2023, 108651
- [4]. "An Overview of Battery Cooling Systems for Electric Vehicles Nguyen Tien Han, Nguyen Thi Hong Ngoc, Nguyen Dinh Tan, Tran Duc Hoang, Nguyen Thanh Cong, Le Van Quynh. World Journal of Research and Review (WJRR) ISSN: 2455-3956, Volume-16, Issue-6, June 2023 Pages 16-22"
- [5]. "Multi-objective optimization of efficient liquid cooling-based battery thermal management system using hybrid manifold channels". Zengguang Sui a, Haosheng Lin a, Qin Sun b, Kaijun Dong b, Wei Wu a. Applied Energy Volume 371, 1 October 2024, 123766
- [6]. "Coupled electrochemical thermal modelling of a novel Li-ion battery pack thermal management system". S. Hariharan a, Subramanya Mayya Kolake a, Taewon Song b, Dong Kee Sohn b, Taejung Yeo b. Applied Energy Volume 181, 1 November 2016, Pages 1-13
- [7]. "Cooling capacity of a novel modular liquid-cooled battery thermal management system for cylindrical lithium ion batteries". Haitao Wang, Tao Tao, Jun Xu, Xuesong Mei, Xiaoyan Liu, Piao Gou. Applied Thermal Engineering Volume 178, September 2020, 115591

- [8]. S. Wiriyasart al. “Thermal management system with nanofluids for electric vehicle battery cooling modules”. Case Studies in Thermal Engineering journal homepage, April 2020, 100583.
- [9]. Mr. Gaurav Raj Pandey, “APPLICATION OF NANO – THERMOFLUIDS IN BATTERY COOLING SYSTEM TO IMPROVE THE PERFORMANCE AND EFFICIENCY OF ELECTRIC VEHICLES”. International Research Journal of Modernization in Engineering Technology and Science (Peer-Reviewed, Open Access, Fully Refereed International Journal) Volume: 06/Issue:06/June-2024 Impact Factor- 7.868.
- [10]. “Numerical investigations on heat transfer enhancement and energy flow distribution for interlayer battery thermal management system using Tesla-valve mini-channelcooling”.Chenguang Lai a b,Shumin Shan a, Shuai Feng a b, Yong Chen a, Junxiong Zeng a, Jie Song a, Lijuan Fu a.Energy Conversion and Management Volume 280, 15 March 2023, 116812
- [11]. Hwang, F. S., Confrey, T., Scully, S., Callaghan, D., Nolan, C., Kent, N., and Flannery, B., 2020, “MODELLING OF HEAT GENERATION IN AN 18650 LITHIUM-ION BATTERY CELL UNDER VARYING DISCHARGE RATES,” Proceeding of 5th Thermal and Fluids Engineering Conference (TFEC), Begellhouse, New Orleans, LA, USA, pp. 333–341.
- [12]. Xing, J., Liu, Z., Huang, P., Feng, C., Zhou, Y., Zhang, D., and Wang, F., 2013, “Experimental and Numerical Study of the Dispersion of Carbon Dioxide Plume,” Journal of Hazardous Materials, 256–257, pp. 40–48.