Hydraulic and Civil Engineering Technology VIII
M. Yang et al. (Eds.)

doi:10.3233/ATDE230786

Computational Analysis of Heat Dissipation Strategies in Li-Ion Battery System Using Aluminium 7075 and Aluminium 6061

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Abstract. This study examines the thermal behaviour of batteries by doing a computational fluid dynamics (CFD) analysis on them using ANSYS. The analysis focuses on various heat sink configurations, including situations without heat sinks as well as those with aluminium alloys 7075 and 6061 of varying thicknesses. The purpose of this study is to determine how effective various setups are in preventing thermal runaway and maintaining temperature rises that are acceptable within predetermined parameters. The findings demonstrate that thicker heat sinks are more effective in improving heat dissipation and the overall performance of battery cooling systems. The comparisons made between the various materials and thicknesses provide insights into the most effective design for heat management systems. In the end, this research contributes to enhanced battery safety, performance, and longevity. Additionally, it serves as a vital reference for engineers and researchers working to advance energy storage technology across a variety of applications.

Keywords. CFD analysis, MSMD battery model, thermal runaway mitigations, battery thermal management, heat sinks.

1. Introduction

In the ever-changing sector of energy storage, batteries are critical for many applications. These uses include groundbreaking electric automobiles, portable electronics, and increasing renewable energy systems. The growing demand for high-performance, safe batteries emphasizes the need to understand their complicated thermal dynamics. As the search for better, longer-lasting energy storage options grows, understanding battery thermal complexity is essential to maximising their potential. Thermal runaway spread is an ever-present problem in battery technology. It is a grave risk that requires constant study [1]. Studies look into how these hot rages start, how they spread, and how they end. Experiments that cover a wide range of battery types and working environments can spot a lot about the complex thermal cascades that are typical of different battery types and operational settings [1-3]. Battery Thermal Management Systems (BTMS) make it possible to extend the life of batteries and make

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them work as well as possible. The most important part of this arsenal of thermal tools, which includes cooling with air, liquid, and phase-change materials, is still controlling temperature [4-6]. Temperatures that are too high or too low hurt productivity and power output, respectively. The most important part of this quest is optimising BTMS, which is a careful process that needs accurate modelling to predict how heat will behave and simplify building plans. Innovative BTMS strategies are born when economic needs and the complexity of system integration come together. These strategies usher in a time when batteries work better for many different uses. The mystery of thermal contact resistance is a key factor in controlling the temperature of electronic devices and batteries [8-10].

This work uses computational fluid dynamics (CFD) analysis to investigate battery heat management in detail. This research explores the thermal qualities and possible efficacy of batteries in specially designed aluminium 6061 and 7075 alloy casings. The study seeks to uncover these batteries' thermal runaway mitigation capabilities. Increased technological advancements have changed several sectors and shaped contemporary growth. The manuscript is arranged in such a way that this section will be followed by methodology and materials, followed by results and critical discussion. This will be followed by Conclusion and future recommendations

2. Methods and Materials

2.1. Selecting a Battery Model

Li-ion batteries behave differently during thermal runaway; therefore, choosing the right battery type is vital. There are many battery models with pros and cons. The simulation details and parameterization data determine the model. The MSMD battery model was chosen for this research because it can simulate macroscopic and microscopic Li-ion battery events [10,12].

2.2. MSMD Battery Model Validation

After developing and parameterizing the MSMD battery model, validation was essential for accuracy and dependability. The model's simulation findings were compared to Li-ion battery thermal runaway test temperature observations. The validation procedure examined three thermal runaway instances with varying setups and heat sinks. The simulation findings were compared to experimental temperature distributions and heat dissipation rates at varied time intervals. The validation showed that the MSMD battery model successfully predicted Li-ion battery thermal runaway. The simulation findings matched experimental data, verifying the model's capacity to forecast battery temperature changes and thermal runaway propagation [11,12].

2.3. Battery Methods and Materials

Understanding and controlling thermal runaway occurrences is crucial for safer and more dependable battery systems. Thermal runaway is an unregulated, self-sustaining temperature rise in a battery cell or pack that may cause fire or explosion. Researchers and engineers use modern methodologies, including CFD simulations, Multiphysics modelling, and heat management strategies, to solve this crucial problem. These subject covers battery thermal runaway analysis methodologies and materials, including CFD, modelling, meshing, and thermal management. The batter model material was Li-Ion [11,12]

2.4. Battery Pack Geometry and Meshing

Battery pack geometry must be accurately represented for successful CFD simulations. Battery cells, cooling systems, and housing make up the battery pack. Simulations closely match real-world circumstances by creating a detailed 3D representation of the complete system. The battery pack geometry is based on thorough measurements and specifications of the battery system under examination. The complicated component geometries and spatial arrangements are thoroughly modelled in the CAD model. To capture details, electrode designs, current collectors, and cooling channels are focused on.

3. Results

The full thermal management study for a 3-cell Li-ion battery is presented and discussed in this section.

3.1. Simulation Setup

The realistic depiction of the 3-cell Li-ion battery in CFD software underpins the investigation. 3D model based on the battery cell size and attributes and the recommended heat sink configurations was made. A specialist CFD software tool simulated complicated fluid flow and heat transfer processes, allowing an exact thermal behaviour study. The battery cells were initially adjusted at 25°C to simulate normal operation. The simulation duration was designed to represent the whole thermal reaction during heat dissipation tests, which are known to cause thermal runaway. The laboratory calorimetry measurements were used to simulate battery cell heat production. This calibration guaranteed that the heat production model appropriately reflected cell behaviour under diverse operating circumstances.

3.2. Battery Module Thermal Runaway Propagation and Mitigation

After understanding the thermal behaviour of the trigger cell, thermal runaway propagation is investigated in the battery module for several heat sink topologies. The main objective was to test heat sink installations for thermal runaway mitigation and battery safety. Three heat sink configurations were used for thermal runaway tests:

- Case-Baseline: Without a heat sink, cascade failure ensued. The battery module failed catastrophically when thermal runaway spread from one cell to another without a heat sink. This is shown in figure 1.

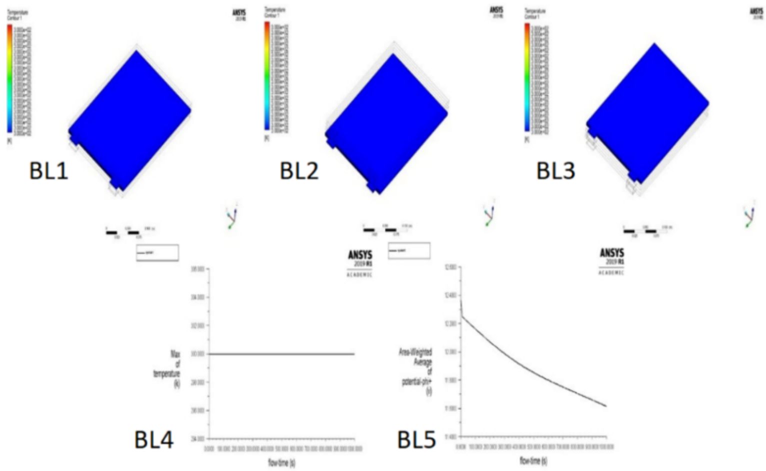

Figure 1. Temperature contour of Lithium-ion battery model without heat sinks in between the cells. BL1, BL2 and BL3 are the temperature contours of cell 1, cell2 and cell 3 respectively. BL4 and BL5 shows the temperature VS flowtime (K-S) and potential VS flowtime (V-S) graph respectively.

- Case-A1: Implemented a 0.8-mm-thick 7075 aluminium heat sink. This experiment examined how well a thin aluminium heat sink contained thermal runaway. This is shown in figure 2.

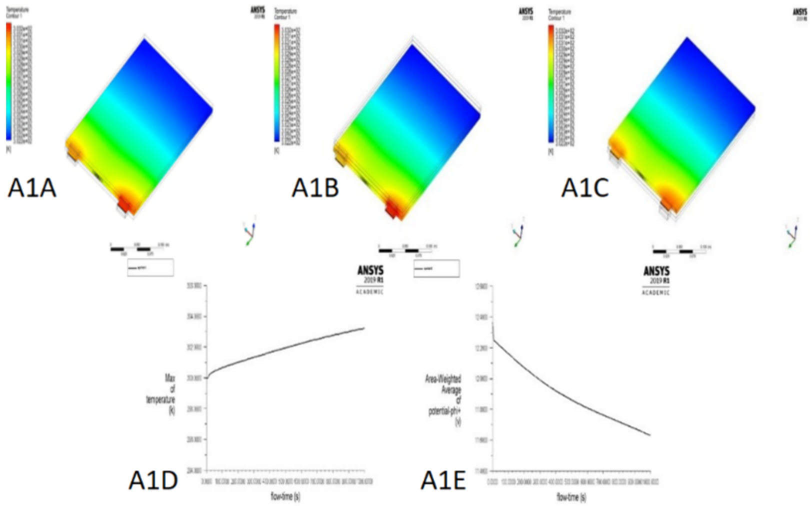

Figure 2. Temperature contour of Lithium-ion battery model with 0.8mm thickness of aluminium 7075 heat sinks in between the cells. A1A, A1B and A1C are the temperature contours of cell 1, cell2 and cell 3 respectively. A1D and A1E shows the temperature VS flowtime (K-S) and potential VS flowtime (V-S) graph respectively.

In comparison, Case-A2 had a thicker aluminium heat sink (3.2 mm). The main goal was to determine how heat sink thickness affects thermal runaway propagation. This is shown in figure 3.

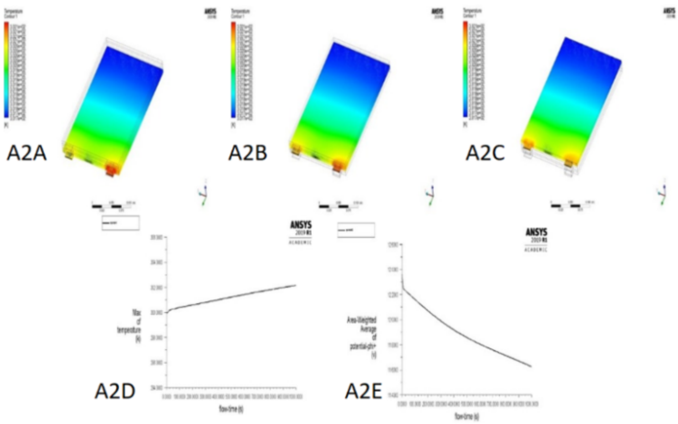

Figure 3. Temperature contour of Lithium-ion battery model with 3.2mm thickness of aluminium 7075 heat sinks in between the cells. A2A, A2B and A2C are the temperature contours of cell 1, cell2 and cell 3 respectively. A2D and A2E shows the temperature VS flowtime (K-S) and potential VS flowtime (V-S) graph respectively.

Comparing Case-Baseline simulation findings to thermal couple measurements showed that thermal runaway propagated from the trigger cell to the battery module in 2 minutes. The simulation and test results matched well, proving the computational model's correctness and dependability. The simulation findings for Case-A1, which used the 3.2-mm aluminium heat sink, were very different. This configuration stopped thermal runaway from spreading beyond the trigger cell. Adjacent cells had no thermal runaway reactions since their peak temperatures were substantially below critical levels. These findings showed that the heat sink layout is crucial to preventing thermal runaway in the battery module. The thicker aluminium heat sink effectively absorbed and dissipated heat from the trigger cell, preventing thermal runaway from spreading to nearby cells.

3.3. Heat Sink Design and Thermal Runaway Mitigation

It was planned to learn more about how heat sink design affects battery module thermal runaway, building on the preceding part. Several simulation instances were investigated with various heat sink configurations to find thermal management design considerations. Two further simulations were run:

- Case-B1: Similar geometry as Case-A2, but with four times the aluminium plate density. The goal was to assess thermal runaway mitigation with higher density.

Figure 4 shows the temperature contour of Lithium-ion battery model with 0.8mm thickness of aluminium 6061 heat sinks in between the cells. B1A, B1B and B1C are the temperature contours of cell 1, cell2 and cell 3 respectively. B1D and B1E shows the temperature VS flowtime (K-S) and potential VS flowtime (V-S) graph respectively.

In Case-B2, the aluminium plate density remained the same as in Case-A2. An increased surface area was tested for heat dissipation efficiency.

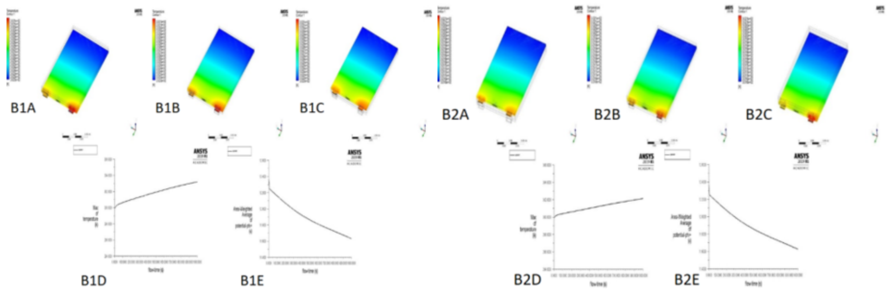

Figure 4. The temperature contour of Lithium-ion battery model with 3.2mm thickness of aluminium 6061 heat sinks in between the cells. B2A, B2B and B2C are the temperature contours of cell 1, cell2 and cell 3 respectively. B2D and B2E shows the temperature VS flowtime (K-S) and potential VS flowtime (V-S) graph respectively.

The simulations for Case-B1 and Case-B2 demonstrated that thermal mass prevents battery module thermal runaway. Cells next to the trigger cell (Cell 2) had average temperatures below 120°C in both instances, suggesting no thermal runaway propagation. Despite having a larger surface area, Case-B2's aluminium plates have the same thermal mass as Case-A2. This showed that thermal mass mitigated thermal runaway more than surface area. It was also acknowledged that bigger or denser heat sinks might increase battery module weight. This may impair battery energy density and performance. In actual applications, temperature control and battery performance must be balanced. To address this worry, how heat sink form and orientation affect heat dissipation efficiency is examined. This might improve heat transmission and dissipation without increasing thermal mass by adjusting heat sink fin geometry and orientation.Also investigated integrating external cooling systems with the heat sink to increase heat dispersion. Forced air or liquid cooling may remove excess heat from the battery module, particularly in high-demand or harsh weather circumstances.

4. Conclusion

ANSYS software and CFD simulations were used to study the thermal properties of a 3-cell lithium-ion (Li-ion) battery when it was exposed to different heat sink configurations. The research examined the effectiveness of several heat sink layouts in preventing thermal runaway, a major lithium-ion battery safety problem. Five heat sink configurations, including a baseline without heat sinks and scenarios with aluminium heat sinks of various thicknesses and compositions were examined. The simulation results revealed how heat sink layouts affect battery thermal management and safety.

The main findings are as follows:

The baseline (Case 1) without a heat sink caused thermal runaway and battery module failure. However, aluminium heat sinks in Cases 2, 3, 4, and 5 alleviated thermal runaways to different degrees. To reduce thermal runaway situations, effective cooling systems are essential.

The findings show that heat sink material and thickness significantly inhibit thermal runaway propagation. In particular, bigger aluminium 6061 heat sinks (Cases 4 and 5) performed better than thinner aluminium 7075 heat sinks (Cases 2 and 3). Aluminium 6061 heat sinks absorb and spread heat because of their increased thermal mass, reducing thermal runaway in nearby cells.

Inter-cellular heat exchange allows heat transmission during thermal runaway to move downstream and upstream within cells, according to models. Aluminium heat sinks improve thermal management and reduce battery module temperature rise by changing heat transfer paths.

Increasing thermal contact resistance between cells and heat sink plates can stop thermal runaway. Thermal contact resistance increased the temperature difference between cells and plates, preventing heat from flowing from upstream to downstream cells and improving cooling.

The research also suggested modifying heat sink design for better thermal management. Changing the shape and structure of an aluminium heat sink improves heat dissipation and prevents localised hotspots, thereby improving battery safety.

It's crucial to understand the research's limitations. The simulations used a specific battery and heat sink. The actual implementation of this technique may need additional testing with different battery combinations, materials, and environments. Additionally, the models were based on assumptions. More comprehensive electro-thermal-coupled models that include electrochemical processes and cell degradation are advised to better understand battery performance.

References

[1] Shahid S & Agelin-Chaab M. A review of thermal runaway prevention and mitigation strategies for lithium-ion batteries. Energy Conversion and Management: X. 2022; 16: 100310.

[2] Zhu M, Yao J, Qian F, Luo W, Chen Y, Zhao L & Chen M. Study on thermal runaway propagation characteristics of lithium iron phosphate battery pack under different SOCs. Electronics. 2013: 200.

[3] Zhu J, Wierzbicki T & Li W. A review of safety-focused mechanical modelling of commercial lithium-ion batteries. Journal of Power Sources. 2018; 378: 153–168.

[4] Fotouhi A, Auger DJ, Propp K, Longo S & Wild M. A review on electric vehicle battery modelling: From lithium-ion toward lithium–sulphur. Renewable and Sustainable Energy Reviews. 2016; 56: 1008–1021.

[5] Zhang W, Ouyang N, Yin X, Li X, Wu W & Huang L. Data-driven early warning strategy for thermal runaway propagation in Lithium-ion battery modules with variable state of charge. Applied Energy. 2022; 323: 119614.

[6] Çetin İ, Sezici E, Karabulut M, Avci E & Polat F. A comprehensive review of battery thermal management systems for electric vehicles. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. 2022;3: 237.

[7] Li W, Zhou Y, Zhang H & Tang X. A review on battery thermal management for new energy vehicles. Energies, 2023; 16: 4845.

[8] Wang AL & Zhao J. Review of prediction for thermal contact resistance. Science China Technological Sciences. 2010; 53: 1798–1808.

[9] Li J. Zhu Q & Sun J. Study on thermal contact resistance at liquid–solid interface based on fractal theory. AIP Advances. 2021; 11: 125308–125308.

[10] Christy TV, Murugan N & Kumar S. A comparative study on the microstructures and mechanical properties of Al 6061 alloy and the MMC Al 6061/TiB2/12p. Journal of Minerals & Materials Characterization & Engineering. 2010; 9: 57-65.

[11] Li Q, Yang C, Santhanagopalan S, Smith K, Lamb J, Steele LA & Torres-Castro L. Numerical investigation of thermal runaway mitigation through a passive thermal management system. Journal of Power Sources. 2019; 429: 80–88.

[12] Fu R, Xiao M & Choe SY. Modelling, validation and analysis of mechanical stress generation and dimension changes of a pouch type high power Li-ion battery. Journal of Power Sources. 2013; 224: 211–224.