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A Numerical Study on Performance Enhancement for the Diversified Shaped Batteries of an Electric Vehicle

Bibhuti Bhusan Nayak*

Mechanical Engineering Department, National Institute of Technology Sikkim, India

***Corresponding Author:** Bibhuti Bhusan Nayak, National Institute of Technology Sikkim, Department of Mechanical Engineering, Ravangla, Sikkim, India.

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Abstract

A numerical study is performed to enhance the performance of electric vehicle batteries of different shapes using different cooling methods. Three cooling approaches were examined: no cooling, water cooling, and the incorporation of nanoparticles in the cooling plate with considering variety of batteries. There are five different setups made for analysis with and without considering flow channels for single and pack up batteries. When the battery pack operated without any cooling mechanism, the maximum temperature (T_{max}) reached approximately 367 K. This finding underscores the inherent thermal challenges associated with uncooled battery systems, as elevated temperatures can lead to reduced efficiency and accelerated degradation. Implementing a water-cooling system resulted in a notable improvement in thermal performance. The T_{max} observed with water cooling was reduced around 354 K. The circulating water effectively dissipated heat from the battery pack, mitigating temperature spikes and enhancing overall thermal stability. The introduction of copper oxide (CuO) nanoparticles into the cooling plate demonstrated the most significant impact on thermal management. The T_{max} recorded with CuO nanoparticles cooling was substantially lower, measuring around 337 K. The findings of this study have significant implications for the design and optimization of cooling systems for the different battery packs. Efficient thermal management, as demonstrated by water cooling and CuO nanoparticles cooling, can extend the lifespan of batteries, improve overall performance, and contribute to the safety of energy storage systems.

Keywords: Electric vehicle; Battery performance enhancement; Li-ion battery; Pouch and cylindrical; cooling channels; Nanofluids; simulation

Introduction

The evolution of electric vehicles (EVs) has been marked by notable strides in technology, yet the challenges of limited mileage, extended charging durations, and quick discharge rates persist. In response to the burgeoning demand for more efficient and sustainable transportation solutions, the present paper seeks to address these challenges by delving into the intricacies of battery thermal management.

Motivated by the current state of EVs, where achieving a significant mileage remains a formidable hurdle, this study aims to redefine the capabilities of electric vehicle batteries. Presently, the average range of EVs hovers around 300 kilometres, and the prolonged charging times act as deterrents to widespread adoption. The urgency to overcome these limitations underscores the critical need for advancements in battery technology.

A meticulous review of the existing literature unveiled a distinctive research gap in the domain of battery thermal management systems (BTMS). This gap presented an opportunity for exploration, leading us to a promising avenue—the integration of Nano Fluid particles in lithium-ion batteries. Notably, the superior specific density of these nanoparticles hinted at their potential to revolutionize the energy storage landscape, thus forming a pivotal aspect of our investigation.

This paper focuses on numerical modelling and simulation, specifically targeting the development and validation of models for Hybrid Battery Thermal Management Systems. The overarching goal is to enhance charging speeds, thereby reducing the overall charging time, and simultaneously improving the performance and energy density of the battery.

Yet, the pursuit of these objectives is not without its share of challenges. The paper entails navigating the complex physics of the BTMS, validating intricate numerical models against real-world scenarios, accounting for the heterogeneous nature of battery packs, considering the environmental impact, and addressing uncertainties that inevitably arise in such groundbreaking research.

Through this paper, we aspire not only to contribute to the academic discourse on electric vehicle battery technology but also to provide tangible solutions that can shape the future of sustainable transportation. The subsequent sections of this report offer a detailed exploration of our methodologies, the results obtained, and the conclusions drawn from our comprehensive numerical investigation. It is our sincere hope that the findings presented herein contribute meaningfully to the ongoing dialogue in the field, propelling us closer to a future where electric vehicles are not only environmentally friendly but also practical, efficient, and widely embraced.

The Evolution of Lithium-ion Batteries

The advent of lithium-ion batteries has undeniably reshaped the landscape of energy storage and portable electronic devices. Originating in the visionary experiments of the 1970s, these batteries have become ubiquitous, powering everything from smartphones to electric vehicles. The journey of lithium-ion batteries is a testament to the relentless pursuit of innovation and the collaborative efforts of scientists, researchers, and engineers worldwide.

In the 1970s, physicist M. Stanley Whittingham laid the groundwork with his groundbreaking work on rechargeable lithium batteries. This initiated a series of discoveries that eventually led to the commercialization of lithium-ion batteries by Sony in 1991. Over the decades, these batteries have undergone remarkable transformations, diversifying in cathode materials, powering the rise of electric vehicles in the 2010s, and continuing to evolve in pursuit of sustainability and resource efficiency.

As we delve into the chronological exploration of the history of lithium-ion batteries, we uncover not only technological advancements but also the stories of perseverance and ingenuity that have propelled this technology to the forefront of our modern energy landscape. Each era brings with it new challenges, breakthroughs, and applications, contributing to the intricate tapestry of the evolution of lithium-ion batteries.

The literature review serves as the foundation for our research by providing a thorough understanding of the existing body of knowledge related to electric vehicle (EV) batteries and their performance enhancement.

The research paper titled "Design and Optimization of a Novel Microchannel Battery Thermal Management System Based on Digital Twin" by Wang et al. (2023) aims to introduce and optimize a novel microchannel Battery Thermal Management System (BTMS) using digital twin technology. The primary objective is to enhance the cooling performance of lithium-ion batteries through an innovative microchannel design and real-time digital simulation. Wang et al. (2023) employed a dual approach involving both physical design and digital twin technology. The researchers designed a microchannel-based BTMS and utilized digital twin simulations to optimize its performance. The digital twin, representing the physical system in real-time, allowed for continuous monitoring and adjustment, contributing to the iterative refinement of the BTMS design. The research demonstrated that the novel microchannel BTMS, optimized using digital twin technology, effectively improves battery cooling performance. The combination of physical design innovation and real-time simulation resulted in a substantial reduction of up to 15°C in the maximum temperature within the battery block. Furthermore, the temperature difference between individual cells was reduced by up to 7°C, showcasing the efficiency of the novel BTMS. The conclusion drawn by Wang et al. (2023) emphasizes the success of the novel microchannel BTMS, showcasing its potential for enhanced thermal management of lithium-ion batteries. The integration of digital twin technology adds a dynamic element, allowing for real-time optimization and adaptability. The findings suggest that this approach holds promise for addressing thermal challenges and improving the overall efficiency and lifespan of lithium-ion batteries in various applications. The research paper titled "A Novel Thermal Management System for Lithium-ion Battery Modules Combining Direct Liquid-cooling with Forced Air-cooling" by Wang et al. (2022) aims to introduce and assess the effectiveness of a novel thermal management system for lithiumion battery modules. The primary objective is to combine direct liquid-cooling and forced air-cooling to optimize battery temperature control, ensuring improved performance, safety, and longevity. Wang et al. (2022) employed a combination of experimental and numerical methods to evaluate the proposed thermal management system. The researchers designed and implemented a system that integrates direct liquidcooling and forced air-cooling. Experimental data were collected to assess the real-world performance of the system, and numerical simulations were conducted to analyze its thermal behavior under various operating conditions. The research demonstrated that the novel thermal management system, combining direct liquid-cooling with forced air-cooling, effectively reduces the maximum temperature within the battery block. The experimental results indicated a reduction of up to 10°C in the maximum temperature, showcasing the system's efficiency in mitigating thermal challenges associated with lithium-ion batteries. The conclusion drawn by Wang et al. (2022) emphasizes the success of the novel thermal management system in effectively reducing the maximum temperature within lithium-ion battery modules. The integration of direct liquid-cooling with forced air-cooling offers a comprehensive solution for addressing thermal challenges, providing benefits in terms of safety, performance, and overall battery lifespan. The findings suggest that this hybrid approach holds promise for practical implementation in various applications requiring efficient thermal control for lithium-ion batteries. The research paper titled "Hybrid Battery Thermal Management System in Electrical Vehicles" by Sun et al. (2022) aims to investigate and propose a hybrid Battery Thermal Management System (BTMS) specifically designed for electric vehicles. The primary objective is to enhance the thermal management of batteries, focusing on maintaining an even temperature distribution, reducing peak temperatures, and improving overall battery performance and safety. Sun et al. (2022) utilized a combination of experimental and numerical methods to evaluate the proposed hybrid BTMS. The researchers designed and implemented a system that integrates air cooling with phase change material (PCM). Experimental data were collected to assess the real-world performance of the system, and numerical simulations were conducted to analyze its thermal behavior under various driving conditions. The research demonstrated that the hybrid BTMS, combining air cooling with phase change material, effectively maintains an even temperature distribution within the battery pack of electric vehicles. The experimental results indicated a reduction of up to 5.0°C in the maximum temperature within the battery pack compared to an air-cooled BTMS. Additionally, the temperature difference between individual cells was reduced by 1.0°C, highlighting the efficiency of the hybrid system. The conclusion drawn by Sun et al. (2022) emphasizes the success of the hybrid BTMS in maintaining an even temperature distribution within the battery pack of electric vehicles. The integration of air cooling with phase change material offers a comprehensive solution for addressing thermal challenges, providing benefits in terms of safety, performance, and overall battery longevity. The findings suggest that this hybrid approach is wellsuited for practical implementation in electric vehicles, contributing to the advancement of electric vehicle battery technology. The research paper titled "Numerical Study on Power Battery Thermal Management System Based on Heat Pipe Technology" by Xu et al. (2022) aims to conduct a comprehensive numerical study on a power battery thermal management system (BTMS) utilizing heat pipe technology. The primary objective is to assess the effectiveness of heat pipes in enhancing the thermal performance of power batteries, with a focus on reducing temperature gradients, improving cooling efficiency, and extending battery life. Xu et al. (2022) employed numerical simulations to investigate the thermal behavior of the power battery system incorporating heat pipe technology. The researchers developed a detailed numerical model to represent the heat transfer processes within the battery pack. The study focused on evaluating temperature distribution, heat dissipation, and the overall thermal performance of the system under different operating conditions. The research demonstrated that the power battery thermal management system utilizing heat pipe technology effectively improves cooling performance. The numerical simulations indicated a reduction of up to 3.0°C in the maximum temperature within the battery pack. The study also revealed that the use of heat pipes can significantly reduce temperature differences between cells, contributing to a more uniform temperature distribution and potentially extending battery life. The conclusion drawn by Xu et al. (2022) emphasizes the positive impact of heat pipe technology on the thermal management of power batteries. The integration of heat pipes offers a viable solution for improving cooling efficiency, reducing temperature variations, and enhancing the overall performance and longevity of power batteries. The findings suggest that heat pipe technology holds promise for practical implementation in power battery systems, contributing to advancements in electric vehicle and energy storage technologies. The research paper titled "Two-Phase Immersion Cooling with Surface Modifications for Thermal Management" by Yin et al. (2022) aims to explore and optimize the thermal management of power systems, specifically focusing on the application of two-phase immersion cooling with surface modifications. The primary objective is to investigate the effectiveness of this cooling technique in enhancing heat dissipation, maintaining lower temperatures, and improving the overall thermal performance of power systems. Yin et al. (2022) conducted a detailed experimental and numerical study to evaluate the thermal management system incorporating two-phase immersion cooling with surface modifications. The researchers implemented surface modifications to enhance heat transfer efficiency and developed a numerical model to simulate the thermal behavior of the system. The study focused on analyzing temperature distribution, heat dissipation, and the impact of surface modifications on the cooling performance. The research demonstrated that the integration of two-phase immersion cooling with surface modifications effectively improves the thermal management of power systems. Experimental results indicated a reduction of up to 15°C in the maximum temperature within the power system. The study highlighted that surface modifications contribute to increased heat transfer rates, leading to a more efficient cooling process. The conclusion drawn by Yin et al. (2022) underscores the success of two-phase immersion cooling with surface modifications in enhancing the thermal management of power systems. The integration of surface modifications contributes to improved heat transfer efficiency, resulting in lower operating temperatures. The findings suggest that this cooling technique holds promise for practical implementation in power systems, offering benefits in terms of thermal performance, efficiency, and potentially extending the lifespan of electronic components. Xu et al. (2021) studied the Optimization of Liquid Cooling and Heat Dissipation System of Lithium-Ion Battery Packs of Automobile. The objective of this research paper is to optimize the liquid cooling and heat dissipation system employed in lithium-ion battery packs for automobiles. The primary aim is to enhance the thermal management of these batteries, ensuring improved performance, efficiency, and overall safety in electric vehicles. The researchers implemented a systematic approach involving the following key methods:

Thermal Analysis: Conducted a comprehensive thermal analysis to understand the heat distribution within the lithium-ion battery packs during different operational scenarios.

Computational Modelling: Utilized computational models to simulate the behavior of the liquid cooling system and its impact on heat dissipation.

Optimization Techniques: Employed optimization techniques to identify the most effective parameters for enhancing the cooling efficiency of the system.

The research yielded the following key findings:

Improved Heat Dissipation: The optimized liquid cooling system demonstrated significantly improved heat dissipation capabilities, preventing overheating issues in the lithium-ion battery packs.

Enhanced Battery Performance: The optimization led to a notable enhancement in the overall performance of the lithium-ion batteries, contributing to increased efficiency and longevity.

Safety Enhancement: The optimized cooling system played a crucial role in ensuring the safety of the battery packs, minimizing the risk of thermal-related incidents.

The research concludes that the optimization of liquid cooling and heat dissipation systems is instrumental in addressing thermal challenges associated with lithium-ion battery packs in automobiles. The findings have practical implications for the automotive industry, emphasizing the significance of efficient thermal management for ensuring the performance, longevity, and safety of electric vehicle batteries.

The primary objective of this paper is to improve the efficiency and thermal management capabilities of packed lithium-ion batteries of various shapes. From the literature review it is found that there is limited research on comparison of performance enhancement of EVs Li-ion batteries of different shapes. In light of the findings from recent research papers, it is aimed to specifically focus on the enhancement of battery thermal management systems (BTMS) using various techniques. The following objectives guide my endeavour:

1. ***Integration of Liquid Cooling Technologies***: Investigate and implement liquid cooling technologies to enhance the thermal management of lithium-ion batteries, drawing insights from recent studies such as Ling et al. (2023) and their use of hybrid BTMS.
2. ***Evaluation of Hybrid BTMS Configurations***: Explore the effectiveness of hybrid BTMS configurations by combining different cooling methods, such as liquid cooling with phase change materials (PCM) or air cooling. This aligns with the conclusions drawn by Zou et al. (2023) and Wang et al. (2022), emphasizing the improvements in battery cooling performance and extended battery life.
3. ***Incorporation of Innovative Cooling Systems***: Explore the use of unconventional cooling systems, such as U-shaped and Z-shaped pipes as studied by Xu et al. (2022), to enhance the cooling performance of aircooled battery packs.

The numerical design, setup, and preliminary results are found in the following sections.

Materials and Methods

Methodology

Thermal Simulation Analysis of Cooling and Heat Dissipation of Lithium Battery Pack

The methodology employed for the thermal simulation analysis of cooling and heat dissipation in a lithium battery pack is structured to comprehensively investigate the intricate thermal dynamics within the system. The objective is to optimize the cooling mechanism for enhanced battery performance and longevity. The following steps outline the key components of the methodology:

Geometry Definition

- Develop a detailed 3D geometric model of the lithium battery pack, including the individual battery cells, cooling plate, and surrounding air.
- Ensure accurate representation of dimensions, material properties, and spatial relationships between components.

Mesh Generation

- Generate a refined mesh to discretize the geometry, facilitating precise simulation of heat transfer and fluid flow.
- Optimize mesh density to balance computational efficiency with the need for capturing temperature variations and fluid dynamics.

Material Properties

- Define thermal properties for materials involved, including the lithium-ion battery cells, cooling plate, and surrounding air.
- Incorporate parameters such as thermal conductivity, specific heat, and density to accurately model heat conduction and storage within the system.

18650 cylindrical LiFePO4 Lithium-ion cell specifications.

Specifications	Value
Cathode material	$LiFePO_4$
Anode material	Graphite
Electrolyte	Carbonate based
Nominal capacity	1500 mAh
Nominal voltage	3.2 V
Dimensions	18mmdiameter × 65mmheight

Boundary Conditions

- Specify initial conditions, setting the starting temperatures for the lithium battery pack, cooling plate, and ambient air.
- Define boundary conditions for convective heat transfer between the battery pack and the cooling plate, accounting for temperature differences.

Fluid Flow Simulation Setup

- Utilize computational fluid dynamics (CFD) techniques to simulate the movement of coolant within the cooling system.
- Implement appropriate models to capture turbulence and assess the flow characteristics, crucial for evaluating thermal efficiency.

Governing Equations

Reynolds Number Assessment

- Evaluate the Reynolds number to determine the flow regime of the coolant.
- Identify whether the flow is in a turbulent regime, impacting the convective heat transfer characteristics.

$$R_e = \frac{\rho v d}{\mu}$$

Heat Transfer Mechanism Modeling

- Model heat transfer between the lithium battery pack and the cooling plate through thermal conduction.
- Apply the energy conservation equation to quantify heat transfer within the battery pack, considering transient conditions.

$$\rho C \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + Q$$

Convective Boundary Condition Definition

- Define convective boundary conditions for the outer surface of the lithium battery cells interacting with the surrounding air.
- Apply the convective heat transfer equation to characterize heat exchange between the battery cells and the ambient air.

$$q = h(T - T_0)$$

Continuity Equation Application

- Implement the continuity equation to ensure mass balance within the cooling system.
- Simulate the movement of coolant within the channels, considering variations in fluid velocity and pressure.

$$\frac{\partial \rho_c}{\partial t} + \nabla(\rho_c v) = 0$$

The methodology integrates principles of heat transfer, fluid dynamics, and material science to conduct a detailed thermal simulation analysis. This approach allows for a comprehensive understanding of the cooling and heat dissipation mechanisms within the lithium battery pack, paving the way for informed design optimizations.

Estimation of Nanofluid Thermophysical Properties

Thermal conductivity of nanofluid was measured using equation $k_{nf} = k_f(1 + 7.47\varphi)$

The density was calculated using equation $\rho_{nf} = (1-\phi)\,\rho_f + \phi\rho_p$

Similarly, the specific heat was determined using equation $$(C_p)_{nf} = \frac{(1-\varphi)(\rho C_p)_{bf} + (\varphi)(\rho C_p)_p}{\rho nf}$$

For the calculation of viscosity of nanofluids equation used, $\mu_{nf} = \mu_f\,(1+39.11\phi + 533.9\phi^2)$

ANSYS Simulation for different set ups

Thermal Analysis of Setup-1 a Plate-Type Lithium-Ion Battery Using ANSYS

The research aims to conduct a comprehensive thermal analysis using ANSYS on a plate-type lithium-ion battery. The battery design includes a Cell Zone (Li) with dimensions of Length: 192mm, Width: 145mm, and Thickness: 2mm. Additionally, separate Cathode and Anode materials (Cu) are integrated into the design, each with dimensions of Length: 45mm, Width: 45mm, and Thickness: 2mm. The meshing process involves an element size of 1.e-003m. The battery capacity is specified as 14.6 Ah.

Geometry and Dimensions

1. Cell Zone (Li)	***2. Cathode & Anode (Cu)***
Length: 192mm Width: 145mm Thickness: 2mm	Length: 45mm Width: 45mm Thickness: 2mm

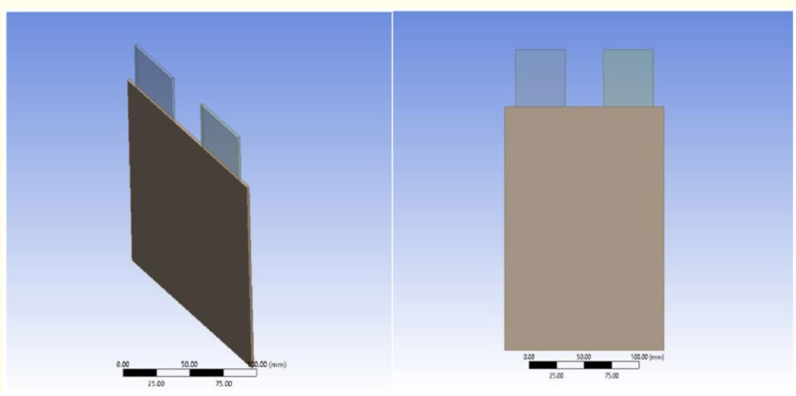

Figure 1: 3D Model of Plate-Type Lithium-Ion Battery.

Meshing

The meshing process is a critical aspect of the simulation, influencing the accuracy and efficiency of the thermal analysis. The chosen element size for the mesh is 1.e-003m, ensuring a fine mesh that captures the intricacies of heat transfer and distribution within the battery components.

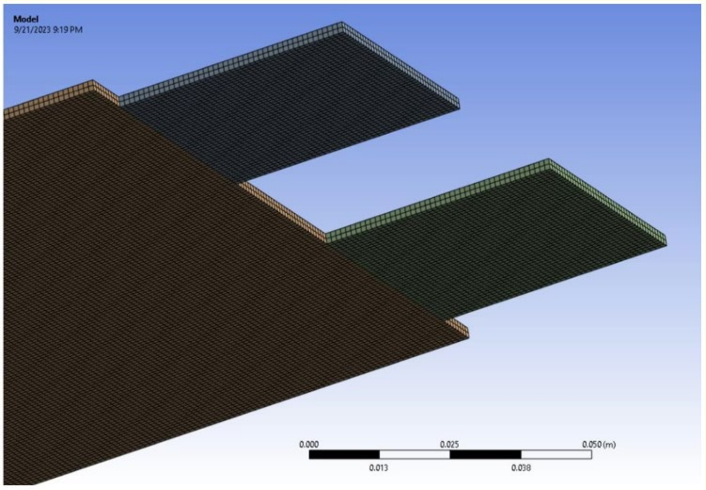

Figure 2: Meshing results of Plate-Type Lithium-Ion Battery.

Material Properties
Cell Zone (Li)

The material properties for the lithium-ion cell, including thermal conductivity, specific heat, and density, will be incorporated based on the specific chemistry and composition of the lithium-ion battery.

Cathode & Anode (Cu)

Copper (Cu) is commonly used for cathode and anode materials. Material properties such as thermal conductivity, specific heat, and density for copper will be implemented in the simulation.

Battery Capacity

The specified battery capacity is 14.6 Ah, providing a crucial parameter for the thermal analysis. The simulation will consider the heat generated during discharge and charge cycles, aiming to evaluate temperature distribution and thermal gradients within the battery.

Simulation Setup
Boundary Conditions

Temperature boundary conditions will be applied to simulate realistic operating conditions. The ambient temperature, initial temperature of the battery components, and any heat exchange with the surroundings will be considered.

Thermal Analysis

The simulation will involve solving the heat transfer equations, accounting for heat generation during charging and discharging cycles. Transient thermal analysis will be employed to observe temperature variations over time.

Detailed ANSYS Simulation Setup-2 for Plate-Type Lithium-Ion Battery Thermal Analysis in which as a coolant water used

In the pursuit of advancing thermal management systems for plate-type lithium-ion batteries, a comprehensive ANSYS simulation setup has been devised. This detailed configuration involves the creation of distinct zones, namely the Cell Zone (Li), Cathode & Anode (Cu), and a dedicated Coolant Channel, each meticulously defined with specific dimensions and materials. The simulation is designed to scrutinize the thermal behavior of the battery under operational conditions, with temperature variations spanning from 300 K to 354 K.

Geometric Configuration

Cell Zone (Li)

- *Dimensions*: Length: 192mm, Width: 145mm, Thickness: 2mm.
- *Material Properties*: Modeled based on lithium-ion cell composition, capturing thermal conductivity, specific heat, and density.

Cathode & Anode (Cu)

- *Dimensions*: Length: 45mm, Width: 45mm, Thickness: 2mm.
- *Material Properties*: Represented with copper (Cu) properties, accounting for thermal conductivity, specific heat, and density.

Coolant Channel

- *Dimensions*: Length: 192 mm, Width: 145 mm, Thickness: 5 mm.
- *Material Properties*: Modeled as a dedicated channel for coolant flow, considering thermal conductivity, specific heat, and density.

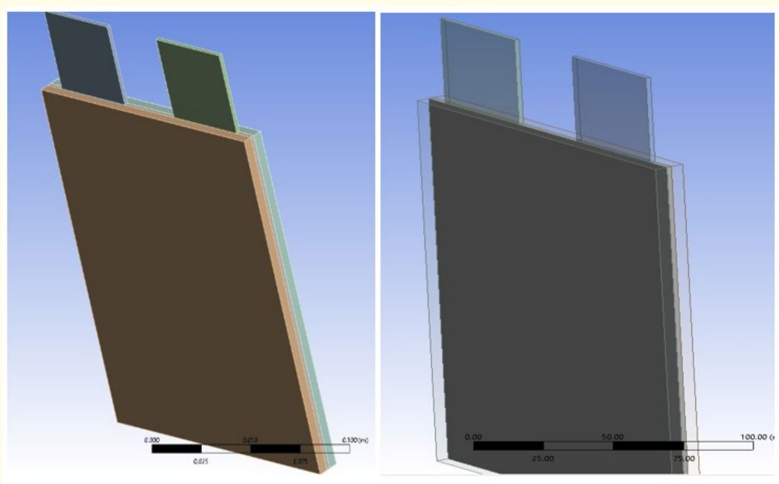

Figure 3: 3D Model of Plate-Type Lithium-Ion Battery with coolant channel.

Meshing Configuration

- *Element Size*: Set at 1.e-003m to ensure a fine mesh, capturing intricate details of heat transfer and distribution within the battery components.
- *Mesh Quality*: Ensured that the mesh quality meets ANSYS simulation standards, optimizing accuracy and computational efficiency.

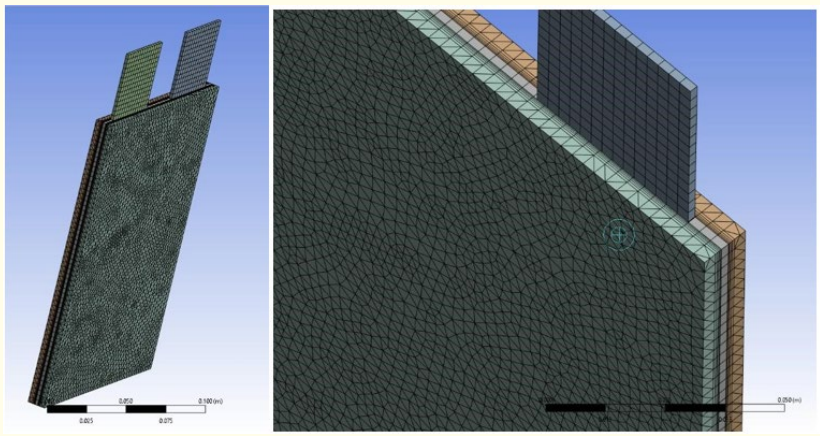

Figure 4: Meshing results of Plate-Type Lithium-Ion Battery with coolant channel.

Boundary Conditions

- *Initial Conditions*: The battery components start with an initial temperature reflecting real-world conditions.
- *Temperature Boundary Conditions*: Varied from 300 K to 354 K to simulate the temperature fluctuations experienced during operational cycles.

Battery Capacity

- *Capacity*: Set at 14.6 Ah, providing a crucial parameter for the thermal analysis. The simulation considers the heat generated during discharge and charge cycles.

Thermal Analysis

- *Transient Thermal Analysis*: Implemented to observe temperature variations over time, capturing dynamic responses during charging and discharging cycles.
- *Heat Transfer Simulation*: Utilized to analyze how efficiently the battery dissipates heat, crucial for preventing overheating and maintaining safe operating temperatures.

Detailed ANSYS Simulation Setup-3 for Plate-Type Lithium-Ion Battery with Nano Fluid Cooling

In the pursuit of enhancing the thermal management system for a plate-type lithium-ion battery, a comprehensive ANSYS simulation setup has been devised. This detailed configuration involves the creation of distinct zones—Cell Zone (Li), Cathode & Anode (Cu), and a dedicated Coolant Channel—each meticulously defined with specific dimensions and materials. The simulation aims to scrutinize the thermal behavior of the battery under operational conditions, considering the influence of a nano fluid cooling system using copper oxide (CuO).

Geometric Configuration

Cell Zone (Li)

- *Dimensions*: Length: 192mm, Width: 145mm, Thickness: 2mm.
- *Material Properties*: Lithium-ion cell properties integrated, capturing thermal conductivity, specific heat, and density characteristics.

Cathode & Anode (Cu)

- *Dimensions*: Length: 45mm, Width: 45mm, Thickness: 2mm.
- *Material Properties*: Modeled with copper (Cu) properties, accounting for thermal conductivity, specific heat, and density.

Coolant Channel

- *Dimensions*: Length: 192mm, Width: 145mm, Thickness: 5mm.
- *Material Properties*: Represents a dedicated channel for coolant flow with thermal conductivity, specific heat, and density parameters.

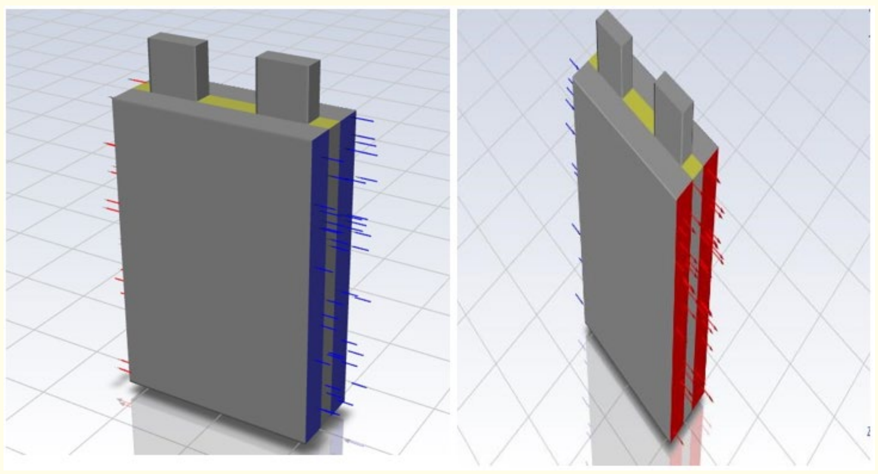

Figure 5: 3D model of Plate-Type Lithium-Ion Battery with Nano Fluid Cooling Channel.

Meshing Configuration

- *Element Size*: Set at 1.e-003m to ensure a fine mesh, capturing intricate details of heat transfer and distribution within the battery components. This meshing refinement is essential for achieving accurate results, especially in areas with complex geometries.
- *Mesh Quality:* Ensured to meet ANSYS simulation standards, optimizing accuracy and computational efficiency. A high-quality mesh is crucial for capturing the nuances of heat dissipation within the battery.

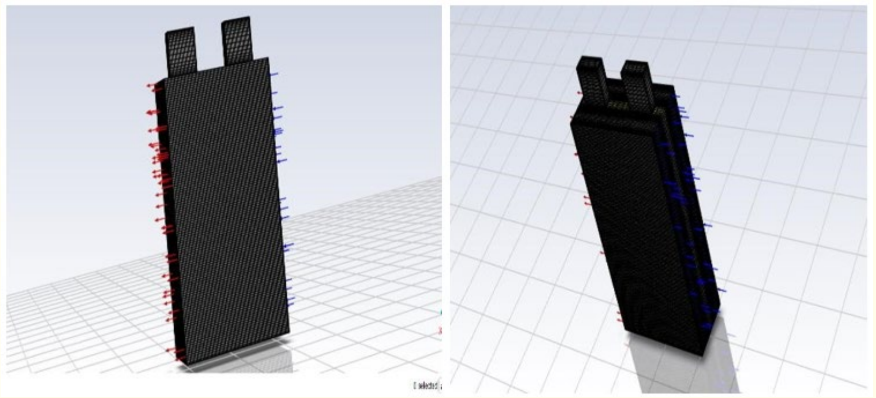

Figure 6: Meshing results of Plate-Type Lithium-Ion Battery with Nano Fluid Cooling Channel.

Boundary Conditions

- *Initial Conditions*: The battery components start with an initial temperature reflecting real-world conditions.
- *Temperature Boundary Conditions*: Varied from 300 K to 337 K to simulate the temperature fluctuations experienced during operational cycles, capturing the full spectrum of thermal dynamics.
- *Fluid Velocity Boundary Conditions*: Velocity varied dynamically during the simulation, ranging from 8.84e+00, representing fluid flow within the coolant channel.

Nano Fluid Configuration

- *Nano Fluid Type*: Copper oxide (CuO) chosen as the nano fluid due to its excellent thermal conductivity and heat dissipation properties.
- *Properties*: The nano fluid properties integrated into the simulation model, accounting for the enhanced thermal conductivity attributed to the presence of CuO nanoparticles.

Battery Capacity

- *Capacity*: Set at 14.6 Ah, providing a crucial parameter for the thermal analysis. The simulation considers the heat generated during discharge and charge cycles, capturing the dynamic nature of battery operation.

Thermal Analysis

- *Transient Thermal Analysis*: Implemented to observe temperature variations over time, capturing dynamic responses during charging and discharging cycles.
- *Fluid Flow Analysis*: Incorporates fluid flow dynamics within the coolant channel, considering the influence of nano fluid properties on heat transfer.

ANSYS Simulation Setup-4 for Cylindrical-Type Lithium-Ion Battery with Water Liquid Cooling

In the pursuit of optimizing the thermal management system for a cylindrical lithium-ion battery pack, a comprehensive ANSYS simulation setup has been devised. This detailed configuration involves the creation of distinct zones—Cell Zone (Li) and a dedicated Coolant Channel—each meticulously defined with specific dimensions. The simulation aims to scrutinize the thermal behavior of the battery pack under operational conditions.

Geometric Configuration

Cell Zone (Li)

- *Dimensions*: Diameter: 18mm, Length: 65mm.
- *Material Properties*: Lithium-ion cell properties integrated, capturing thermal conductivity, specific heat, and density characteristics.

Coolant Channel

- *Dimensions*: Length: 65mm, Thickness: 3mm (around the battery pack)
- *Material Properties*: Represents a dedicated channel for coolant flow with thermal conductivity, specific heat, and density parameters.

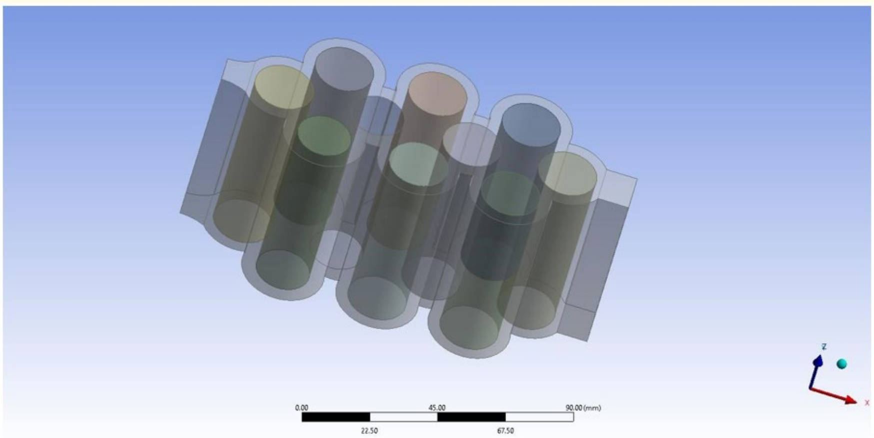

Figure 7: 3D model of Cylindrical-Type Lithium-Ion Battery with Water Liquid Cooling.

Meshing Configuration

- *Element Size*: Set at 0.001 to ensure a fine mesh, capturing intricate details of heat transfer and distribution within the cylindrical battery pack. This meshing refinement is essential for achieving accurate results, especially in areas with complex geometries.
- *Mesh Quality*: Ensured to meet ANSYS simulation standards, optimizing accuracy and computational efficiency. A high-quality mesh is crucial for capturing the nuances of heat dissipation within the battery pack.

Boundary Conditions

- *Initial Conditions*: The battery components start with an initial temperature reflecting real-world conditions.
- *Temperature Boundary Conditions*: Varied from 300 K to 325 K to simulate the temperature fluctuations experienced during operational cycles, capturing the full spectrum of thermal dynamics.

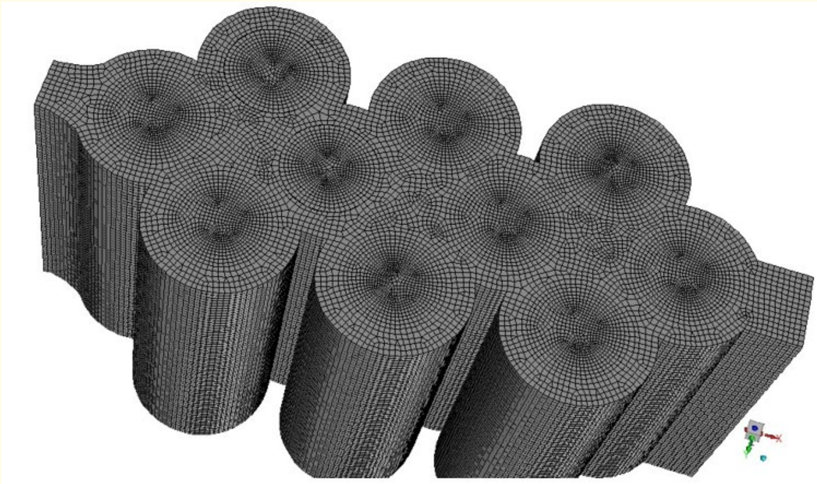

Figure 8: Meshing results of Cylindrical-Type Lithium-Ion Battery with Water Liquid Cooling.

Thermal Analysis

- *Transient Thermal Analysis*: Implemented to observe temperature variations over time, capturing dynamic responses during charging and discharging cycles.
- *Fluid Flow Analysis*: Incorporates fluid flow dynamics within the coolant channel, considering the influence of coolant properties on heat transfer.

ANSYS Modelling Setup-5 for 40 Cylindrical Lithium-Ion Batteries with U-Tube Channel Type Water Liquid Cooling system

In the pursuit of advancing thermal management systems for electric vehicle batteries, an intricate ANSYS modeling setup has been developed for a configuration consisting of 40 cylindrical lithium-ion batteries. This comprehensive simulation incorporates a U-tube channel type water liquid cooling system, aiming to optimize heat dissipation and enhance the overall efficiency of the battery pack.

Geometric Configuration

Cell Zone (Li)

- *Dimensions*: Diameter: 18mm, Length: 65mm.
- *Material Properties*: Lithium-ion cell properties integrated, capturing thermal conductivity, specific heat, and density characteristics.

Coolant Channel

- *Dimensions*: Length: 65mm, Thickness: 3mm (around the battery pack)
- *Material Properties*: Represents a U-tube channel type water liquid cooling system with thermal conductivity, specific heat, and density parameters.

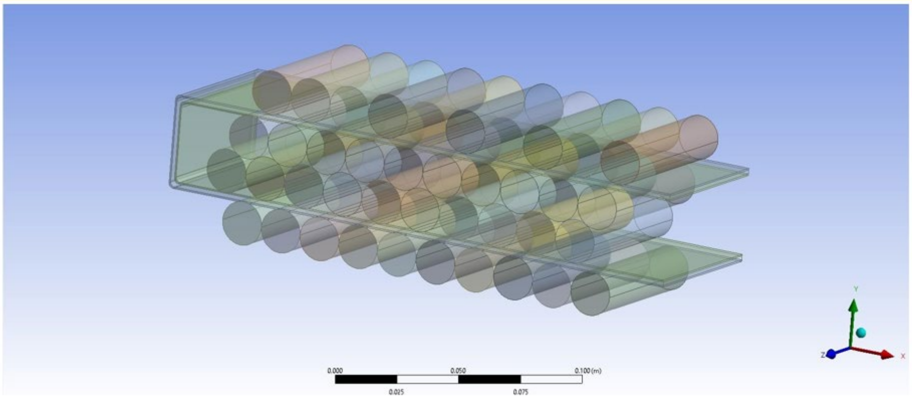

Figure 9: 3D model of 40 nos. of Cylindrical Lithium-Ion Batteries with U-Tube Channel Type Water Liquid Cooling system.

Meshing Configuration

- *Element Size*: Set at 0.001 to ensure a fine mesh, capturing intricate details of heat transfer and distribution within the battery pack. This meshing refinement is essential for achieving accurate results, especially in areas with complex geometries.
- *Mesh Quality*: Ensured to meet ANSYS simulation standards, optimizing accuracy and computational efficiency. A high-quality mesh is crucial for capturing the nuances of heat dissipation within the battery pack.

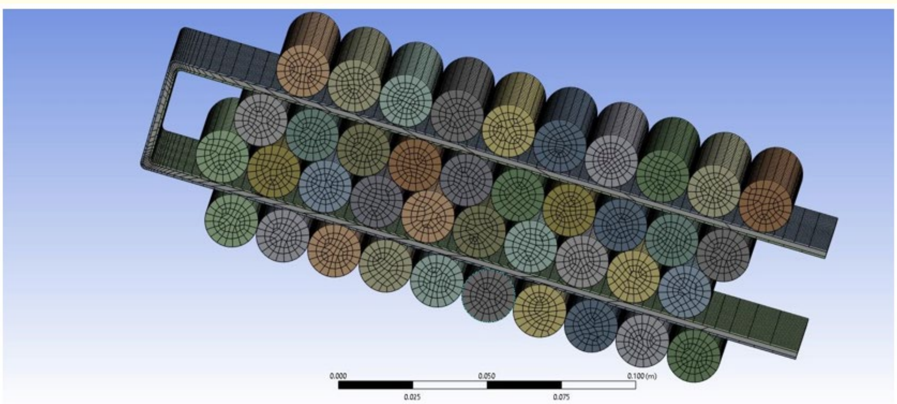

Figure 10: Meshing results of 40 nos. of Cylindrical Lithium-Ion Batteries with U-Tube Channel Type Water Liquid Cooling system.

Boundary Conditions

Initial Conditions: The battery components start with an initial temperature reflecting real-world conditions.

- *Temperature Boundary Conditions*: Varied to simulate realistic operational cycles, ensuring the model captures the full spectrum of thermal dynamics.

- *Fluid Flow Conditions*: The U-tube channel type water liquid cooling system's fluid flow dynamics integrated to simulate the cooling effect on the battery pack.

Thermal Analysis

- *Transient Thermal Analysis*: Implemented to observe temperature variations over time, capturing dynamic responses during charging and discharging cycles.
- *Fluid Flow Analysis*: Incorporates fluid flow dynamics within the U-tube channel, considering the influence of coolant properties on heat transfer.

This detailed ANSYS modeling setup aims to provide a comprehensive understanding of the thermal behavior of the configuration with 40 cylindrical lithium-ion batteries, incorporating a U-tube channel type water liquid cooling system. The outcomes will contribute valuable insights for further design refinements and optimizations, ultimately enhancing the efficiency and reliability of thermal management systems for electric vehicle batteries.

Results and Discussion

Plate-type lithium-ion battery

The simulation aims to provide insights into the temperature distribution within the lithium-ion battery components, highlighting potential areas of thermal stress or inefficiency.

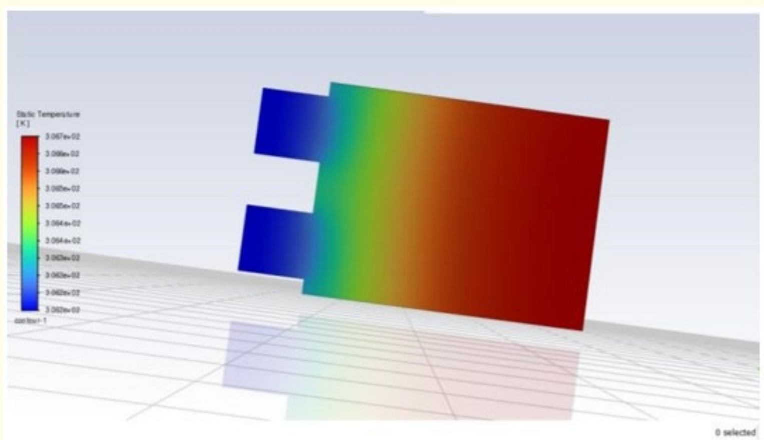

Figure 11: Temperature distribution contour of plate-type lithium-ion battery.

The ANSYS thermal analysis of the plate-type lithium-ion battery is expected to offer valuable insights into its thermal behavior under various conditions. The outcomes will inform future design modifications and enhancements, contributing to the development of efficient and safe lithium-ion batteries for diverse applications.

Plate-type lithium-ion battery with coolant channel

Temperature Distribution: Insights into the temperature distribution within the lithium-ion battery components, identifying potential areas of thermal stress or inefficiency.

Thermal Gradients: Assessment of thermal gradients for evaluating the uniformity of temperature across the battery components.

Heat Dissipation: Evaluation of how efficiently the battery dissipates heat, critical for preventing overheating and ensuring optimal performance.

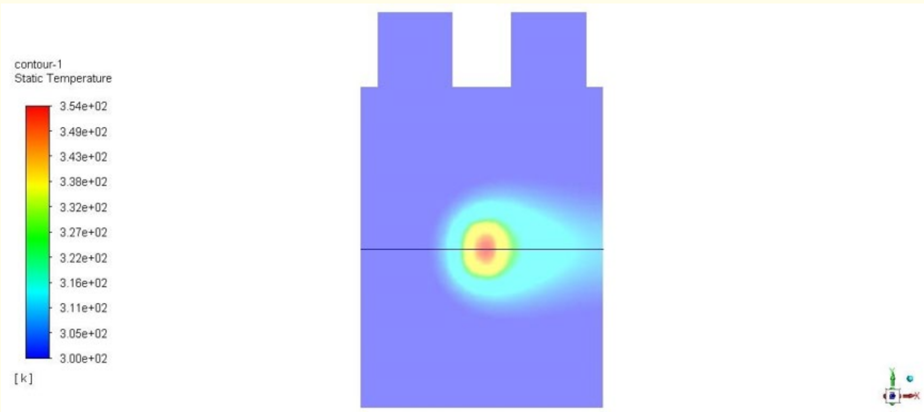

Figure 12: Temperature distribution contour of plate-type lithium-ion battery with coolant channel.

This detailed ANSYS simulation setup aims to provide a comprehensive understanding of the thermal behavior of the plate-type lithium-ion battery under various operational conditions. The outcomes will contribute valuable insights for further design refinements and optimizations, ultimately enhancing the efficiency and reliability of thermal management systems for electric vehicle batteries.

Plate-type lithium-ion battery with Nono fluid coolant channel

- *Temperature Distribution*: Insights into the temperature distribution within the lithium-ion battery components, identifying potential areas of thermal stress or inefficiency.
- *Nano Fluid Cooling Efficiency*: Evaluation of how efficiently the nano fluid (CuO) dissipates heat, contributing to enhanced thermal management and preventing overheating.

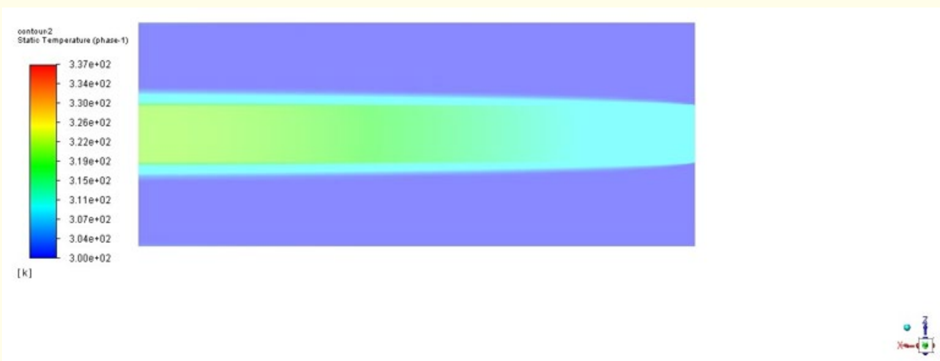

Figure 13: Temperature distribution contour of plate-type lithium-ion battery with Nono fluid coolant channel.

- *Fluid Flow Dynamics*: Analysis of fluid flow patterns within the coolant channel, assessing the effectiveness of the nano fluid in maintaining uniform temperature distribution.

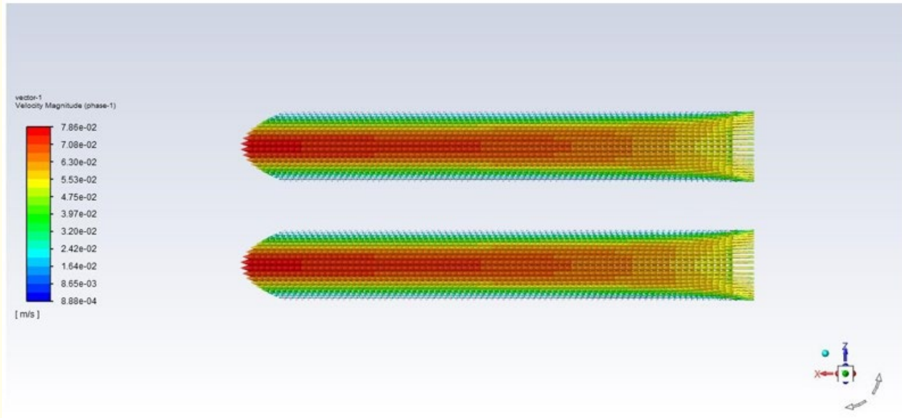

Figure 14: Velocity distribution Contour of plate-type lithium-ion battery with Nono fluid coolant channel.

- *Heat Dissipation*: Assessment of how well the battery dissipates heat, critical for preventing overheating and ensuring optimal performance, with a specific focus on the influence of nano fluid cooling.

This detailed ANSYS simulation setup aims to provide a comprehensive understanding of the thermal behavior of the plate-type lithium-ion battery under various operational conditions, specifically exploring the impact of nano fluid (CuO) cooling. The outcomes will contribute valuable insights for further design refinements and optimizations, ultimately enhancing the efficiency and reliability of thermal management systems for electric vehicle batteries.

Cylindrical-Type Lithium-Ion Battery with Water Liquid Cooling

- *Temperature Distribution*: Insights into the temperature distribution within the cylindrical lithium-ion battery pack, identifying potential areas of thermal stress or inefficiency.
- *Coolant Channel Efficiency*: Evaluation of how efficiently the coolant dissipates heat, contributing to enhanced thermal management and preventing overheating.
- *Heat Dissipation*: Assessment of how well the battery pack dissipates heat, critical for preventing overheating and ensuring optimal performance.

This detailed ANSYS simulation setup aims to provide a comprehensive understanding of the thermal behavior of the cylindrical lithium-ion battery pack under various operational conditions. The outcomes will contribute valuable insights for further design refinements and optimizations, ultimately enhancing the efficiency and reliability of thermal management systems for electric vehicle batteries.

Cylindrical Lithium-Ion Batteries (40 nos.) with U-Tube Channel Type Water Liquid Cooling system

Temperature Distribution: Insights into the temperature distribution within the cylindrical lithium-ion Batteries pack with U-Tube Channel Type Water Liquid Cooling system, identifying potential areas of thermal distribution at various positions of the battery pack and channel.

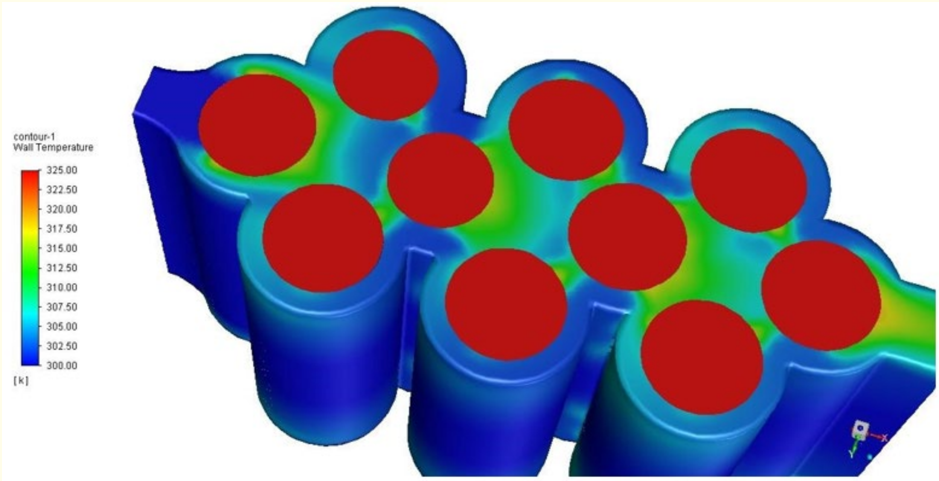

Figure 15: Wall temperature distribution contour of Cylindrical-Type Lithium-Ion Battery with Water Liquid Cooling.

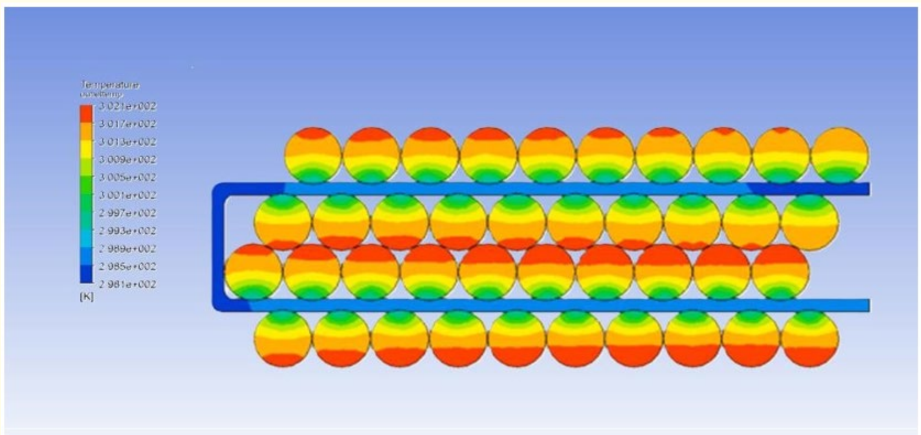

Figure 16: Temperature distribution contours of 40 nos. of Cylindrical Lithium-Ion Batteries with U-Tube Channel Type Water Liquid Cooling system.

It can be observed from the Fig. 16 that the maximum temperature of the U-Tube Channel with water cooling system is 302.10 K, and the coolant input passage is also at the lowest temperature, and the coolant temperature gradually increases from the inlet to the outlet, the simulation result obtained is authentic and trustworthy.

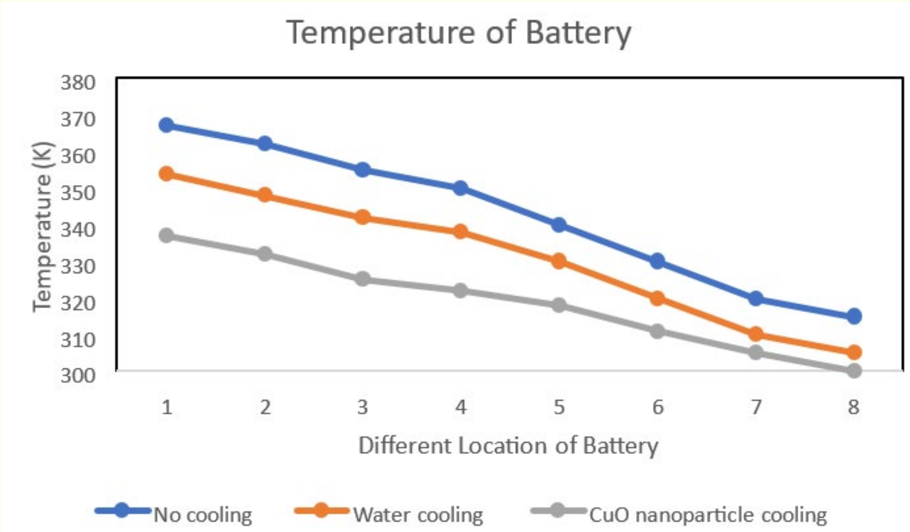

Figure 17: Distribution of temperature using various cooling techniques.

Conclusion

The primary objective of this study was to investigate and compare the thermal performance of various types of battery packs under different cooling methods. Three cooling and heat dissipation approaches were examined: no cooling, water cooling, and the incorporation of copper oxide (CuO) nanoparticles in the cooling plate in various types of Li ion electric vehicle batteries from the aspects of structural rationality, fluid mechanics and heat transfer [Fig.17]. It was observed that coolant is reducing the cooling capacity during the cooling process by absorbing the heat produced by the battery cells. As a result, the temperature downstream is always higher than the temperature upstream. Higher variance distribution will result from inconsistent cooling.

No Cooling

When the battery pack operated without any cooling mechanism, the maximum temperature (T_{max}) reached approximately 367 K. This finding underscores the inherent thermal challenges associated with uncooled battery systems, as elevated temperatures can lead to reduced efficiency and accelerated degradation.

Water Cooling

Implementing a water-cooling system resulted in a notable improvement in thermal performance. The T_{max} observed with water cooling was reduced to around 354 K. The circulating water effectively dissipated heat from the battery pack, mitigating temperature spikes and enhancing overall thermal stability.

CuO Nanoparticles Cooling

The introduction of copper oxide (CuO) nanoparticles into the cooling plate demonstrated the most significant impact on thermal management. The T_{max} recorded with CuO nanoparticles cooling was substantially lower, measuring around 337 K. This suggests that the nanoparticles enhanced heat transfer and dissipation, leading to a more efficient cooling process.

Comparison of various cooling techniques

No Cooling vs. Water Cooling

The comparison between no cooling and water cooling highlights the critical role of active cooling mechanisms in maintaining a favorable thermal environment for battery packs. Water cooling, by removing excess heat, contributed to a considerable reduction in T_{max}, indicating its effectiveness in preventing overheating.

Water Cooling vs. CuO Nanoparticles Cooling

The comparison between water cooling and CuO nanoparticles cooling reveals the superior performance of the latter. The incorporation of CuO nanoparticles enhanced the cooling efficiency, resulting in a lower T_{max}. The nanoparticles likely facilitated better heat transfer within the cooling medium, leading to improved thermal conductivity.

The findings of this study have significant implications for the design and optimization of cooling systems for battery packs. Efficient thermal management, as demonstrated by water cooling and CuO nanoparticles cooling, can extend the lifespan of batteries, improve overall performance, and contribute to the safety of energy storage systems.

Future research may explore the long-term effects of different cooling methods on battery degradation and assess the economic feasibility of implementing advanced cooling technologies. Additionally, investigating the scalability and practicality of CuO nanoparticles cooling in real-world applications could provide valuable insights for industrial adoption.

In conclusion, this study underscores the importance of active cooling methods in maintaining optimal temperatures for battery packs. The results suggest that both water cooling and the integration of CuO nanoparticles offer viable solutions, with the latter showing promising potential for enhancing thermal performance. These findings contribute to the ongoing efforts in developing sustainable and efficient energy storage systems.

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