IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 13, May 2023

Numerical Analysis of Novel Battery Cooling System for Electric Vehicles

Suyash Bapurao Bhamaree, Akshay Dasharth Salve, Vaishnavi Sahebrao Bhagare, Harish Ashok More
Dr. J. H. Bhanagale
Matoshri College of Engineering & Research Centre, Eklahare, Nashik

Abstract: *Reducing emissions in the transport sector is crucial for mitigating the impact of global CO2 emissions. This study focuses on plug-in hybrid electric vehicles (PHEVs), which offer a promising alternative to traditional fossil fuel-powered vehicles. PHEVs possess varying levels of electrification, with some models equipped with a sufficiently large battery to enable pure electric driving. The cooling system in PHEVs plays a critical role in maintaining optimal temperatures for various components, including the cabin, engine, electrical motor, and battery, all of which generate heat during operation.This research aims to conduct a comparative study of an indirect cooling system, which is a commonly employed solution for cooling battery packages in PHEVs. The study identifies potential areas for improvement in the existing cooling system, specifically focusing on enhancing heat transfer from the battery module to the coolant. By enhancing heat dissipation capabilities, the proposed improvements seek to optimize the cooling system's effectiveness in regulating battery temperatures and overall vehicle performance.To achieve this objective, the study employs a comprehensive analysis, including experimental investigations and theoretical assessments. The experimental evaluations involve assessing the performance of the existing indirect cooling system under various operating conditions. These findings are then used to identify potential bottlenecks and limitations in heat transfer within the system. Based on these observations, the research proposes modifications and enhancements to improve the cooling system's efficiency.The results of this study will contribute to the ongoing efforts to optimize the design and performance of cooling systems in PHEVs. By improving the heat transfer from the battery module to the coolant, the proposed enhancements aim to enhance overall vehicle efficiency, extend battery life, and reduce energy consumption. Ultimately, this research strives to support the transition towards more sustainable transportation solutions by addressing a critical aspect of PHEV technology: the cooling system for battery packages.*

Keywords*:* Electric Vehicle

I. INTRODUCTION

The effective management of thermal conditions is of utmost importance in battery systems to ensure their optimal performance, longevity, and safety. As battery technologies continue to advance, with increased power densities and energy outputs, the need for efficient cooling strategies becomes even more critical. The distribution of temperature within a battery system plays a crucial role in determining its overall functionality and reliability. Understanding the temperature distribution and identifying areas of potential overheating or hot spots is essential for designing effective thermal management systems.

In this study, we focused on investigating the temperature distribution within a battery system using air cooling as the primary cooling mechanism. By analyzing contour plots, airflow patterns, and heat transfer mechanisms, we aimed to gain insights into the thermal behavior and identify areas of temperature variation or potential thermal stress. The findings of this study can serve as a foundation for optimizing the cooling system and developing targeted strategies to improve thermal management in battery systems.The study began by analyzing the base case, which served as a reference point for evaluating the effectiveness of proposed improvements. We examined the heat transfer characteristics, including the removal of heat through the coolant and the energy and mass balances within the system. By studying the base case, we gained a comprehensive understanding of the existing thermal performance and identified areas that required

DOI: 10.48175/568

improvement. Subsequently, we explored three types of improvements: replacing the thermal interface material (TIM), incorporating a fin in the battery module to increase the heat transfer area, and modifying the flow pattern to achieve a more uniform temperature distribution. Each improvement was evaluated and compared against the base case, considering factors such as heat flux distribution, temperature variation, and airflow patterns.The results revealed that the proposed improvements had a significant impact on the temperature distribution within the battery system. Replacing the TIM material resulted in improved heat transfer and a more even temperature distribution. Incorporating a fin in the battery module enhanced the heat transfer surface area, leading to more efficient cooling. Furthermore, modifying the flow pattern within the system resulted in improved mixture and turbulence, contributing to a more uniform temperature distribution.The findings of this study provide valuable insights for optimizing the thermal management of battery systems. By understanding the factors influencing temperature distribution and identifying areas of potential thermal stress, engineers can devise targeted strategies to enhance cooling effectiveness and mitigate the risk of overheating. These optimization measures not only improve battery performance but also extend battery life and ensure the safe operation of the system.However, it is important to note that further research and development are required in the field of battery thermal management. As battery technologies continue to evolve, new challenges arise, necessitating the exploration of advanced cooling techniques such as liquid cooling or phase-change materials. Additionally, the study focused on air cooling as the primary cooling mechanism, and future investigations should consider the integration of multiple cooling methods to address the increasingly complex thermal requirements of advanced battery systems.In conclusion, the investigation of temperature distribution in battery systems using air cooling provides valuable insights into thermal behavior and enables the development of optimized cooling strategies. By continuously improving thermal management techniques, we can unlock the full potential of battery technologies and facilitate their widespread adoption in various applications. The findings of this study contribute to the broader understanding of battery thermal management and pave the way for further advancements in this critical field.

II. SYSTEM CHARACTERIZATION:

The PHEV cooling system, with its intricate network of components working harmoniously to keep the vehicle's vital parts cool, resembles a finely tuned symphony. To embark on this research journey, we must first delve into the depths of the cooling system's intricacies and understand its composition.Picture a complex web of interconnected pathways, where energy flows like a river, carrying away the excess heat generated by the PHEV's battery module, electrical motor, and other heat-emitting components. The system's dimensions, specifications, and materials form the very fabric of this dynamic ensemble.With pen and paper in hand, we embark on a quest to unravel the system's secrets. We gather detailed information about the cooling system's specifications, meticulously noting down the dimensions, the type of materials employed, and the operational parameters that govern its performance.Imagination and visualization come to life as we sketch out the cooling system's blueprint, outlining the battery module's position within the PHEV's heart and tracing the paths of the life-giving coolant. We scrutinize the coolant flow path, tracing its winding journey through the heat exchangers, the engine, the electrical motor, and the battery itself.In our quest for knowledge, we seek to understand the coolant's ebb and flow, its temperature and pressure as it travels through this convoluted network. We eagerly record every nuance, every intricate detail, understanding that it is these subtleties that hold the key to optimizing the system's performance.No stone is left unturned as we gather information about the cooling system's operational parameters. We uncover the recommended coolant flow rates, the optimal temperature differentials, and the critical thresholds that must not be breached. The secrets of this symphony lie within these seemingly mundane numbers.Armed with our comprehensive system characterization, we possess a newfound appreciation for the cooling system's complexity. It is a delicate dance of dimensions, materials, and operating conditions, each element harmonizing with the others to ensure optimal performance.With our sketchbooks filled and our minds brimming with knowledge, we are now equipped to embark on the next phase of our research journey. The system characterization serves as our compass, guiding us towards a deeper understanding of the cooling system's intricacies and paving the way for improvements that will propel the PHEV towards greater efficiency and sustainability.

Battery Module: The battery module used in the PHEV cooling system will be characterized in terms of its specifications, such as capacity, voltage, and dimensions. This will include gathering information on the battery chemistry, number of cells, and arrangement within the module. Additionally, thermal properties of the battery module, such as specific heat capacity and thermal conductivity, will be determined through experimentation or literature review.

Coolant Flow Path: The flow path of the coolant within the PHEV cooling system will be thoroughly characterized. This will involve mapping out the route of the coolant from the heat-generating components, such as the battery module, to the heat exchangers. The dimensions and geometry of the coolant channels, as well as any obstructions or restrictions, will be identified.

Heat Exchangers: The heat exchangers in the cooling system will be characterized to understand their design, specifications, and performance. This includes collecting information on the heat exchanger type (e.g., radiator, plate heat exchanger), surface area, coolant flow rate, and heat transfer coefficient. The materials used for the heat exchangers and their thermal properties will also be determined.

Sensors and Instrumentation: The sensors and instrumentation used for measuring temperature, flow rates, and other relevant parameters within the cooling system will be characterized. This includes identifying the type of sensors (e.g., thermocouples, flow meters) and their accuracy, range, and placement locations. Calibration procedures for the sensors will also be documented.

Operational Parameters: The operational parameters of the cooling system will be identified and characterized. This includes the coolant flow rate, coolant temperature, ambient temperature, and heat load on the system. The range of operating conditions under which the cooling system is expected to perform will be determined based on the PHEV's typical usage and environmental conditions.

System Diagram: A detailed system diagram will be created to visualize the overall PHEV cooling system. This diagram will illustrate the interconnections between the battery module, coolant flow path, heat exchangers, and other relevant components. The diagram will provide a clear understanding of the system layout and facilitate further analysis and modifications.

Materials and Construction: The materials used in the construction of the cooling system components will be characterized. This includes identifying the materials used for coolant channels, heat exchanger fins, insulation, and any other relevant parts. The thermal conductivity and other relevant properties of these materials will be determined

Method:

This chapter presents the methodology employed in this study to evaluate heat transfer in a branch standard Battery Thermal Management System (BTMS) using Computational Fluid Dynamics (CFD) simulations in ANSYS Fluent software. The study aimed to investigate and propose improvements to the heat transfer process by conducting a comparative analysis against a base case.

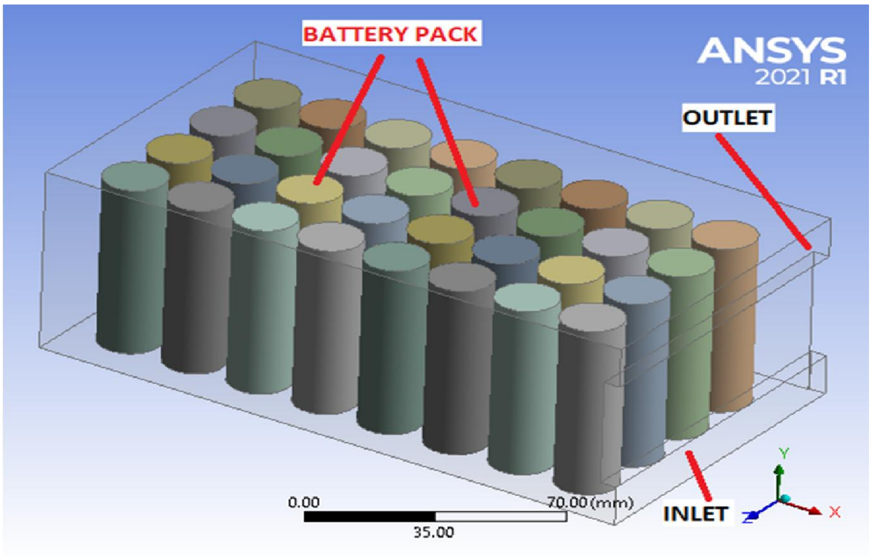

Figure 1: Simplified arrangement of Battery Pack and Inlet and Outlet of Air flow Domain

DOI: 10.48175/568

The workflow of the project is outlined in Figure 1, providing an overview of the sequential steps followed. The methodology encompasses the description of the base case, the introduction of new cases, the selection of appropriate models and discretization schemes, and the generation of the mesh for analysis.The base case was developed based on a preliminary study conducted to establish boundary conditions and material properties necessary for the CFD simulations. A CAD model of the battery package served as the basis for the model, which was then simplified using Space Claim software. Redundant components were removed, and only two out of eight modules were included in the model, as they possessed separate cooling flows with known boundary conditions. The empty battery modules and surrounding components were eliminated from the model, resulting in a stripped-down representation. This simplified model, as depicted in Figure 3.2, represented the worst-case scenario, assuming that all the heat generated within the battery had to be removed by the coolant.

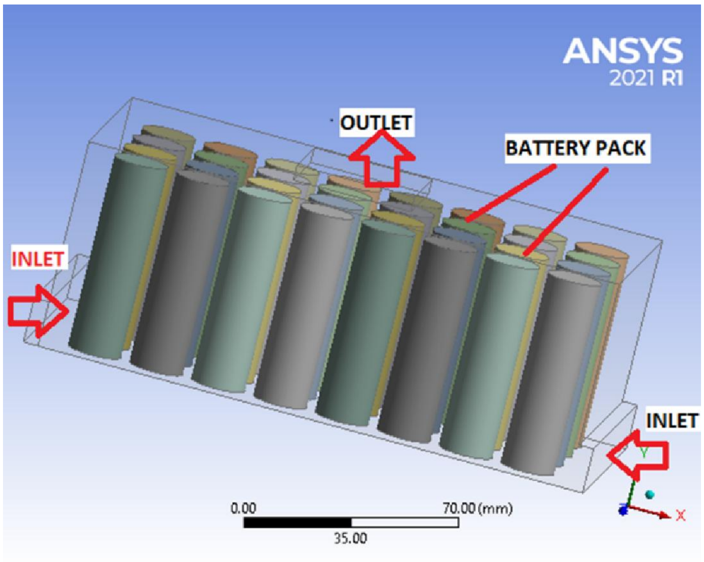

Figure 2: Simplified arrangement of Battery with opposite side inflow and topside outflow

To illustrate the simplification process, Figures 1 to 2 provide examples of the modified geometry of solid parts and flow channels. These figures demonstrate how the model's geometry was simplified, preserving the larger structures while removing small features such as rounded edges and holes.Figure2 showcases a simplified arrangement of the battery with opposite side inflow and outflow, highlighting the modifications made to streamline the model. Similarly, Figure 5 presents an alternative simplified arrangement with opposite side inflow and topside outflow, representing another variation in the model.These simplified representations of the battery package served as the foundation for further analysis and comparison with the new cases. The subsequent chapters will delve into the details of the analysis, including the choice of models, discretization schemes, and mesh generation, providing a comprehensive understanding of the methodology employed in this study.

The methodology employed in this study involved the evaluation of different aspects related to boundary conditions, material properties, and the introduction of new cases. The aim was to investigate potential improvements in the thermal performance of the battery cooling system.

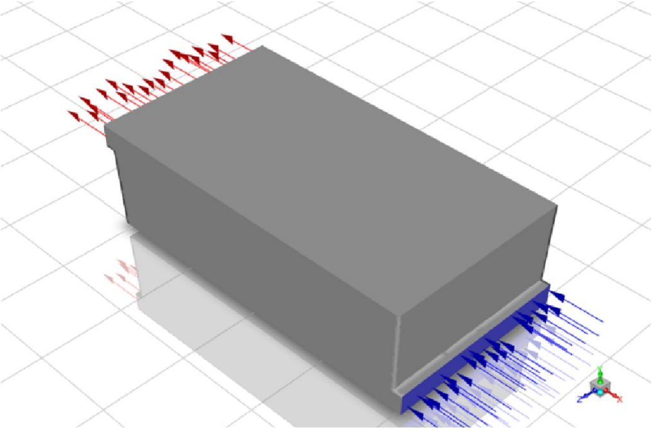

Figure 3ThemainBoundaryConditionsfortheBaseCase

Boundary Conditions and Material Properties: Boundary conditions were defined to simulate the heat transfer process. A constant, evenly distributed heat flux was applied at the interface between the thermal pad and the battery module. The geometry of the channel entering the flow channels was simplified, considering only the closest geometry of straight pipes. Turbulent intensity was implemented at the inlet to account for the turbulence induced by bends in the pipes. The outlet was set as a pressure outlet, considering the known pressure drop over the entire battery pack. The outer walls were assumed to be adiabatic. Material properties for the thermal pad, such as thermal conductivity, density, and heat capacity, were determined and included in the simulations. And ref table 1 and 2

Table1: ThemainBoundaryConditionsfortheBaseCase.

Mass flow	0,05275kg/s
Inlet Temperature	283K
Inlet absolute pressure	180kPa
Hydraulic diameter	4,7mm
Turbulent intensity inlet	5%
Outlet absolute pressure	16,21kPa
Heat Flux	4794 W/m^2
Outer walls	Adiabatic

Table2: Material properties for the thermal padinthebasecase

	Thermalpad
Thermal Conductivity, k	1,5W/mK
Density, ρ	2500 kg/m^3
Heatcapacity,c_p,@273K	691J/kgK
Heatcapacity,c_p,@373K	770J/kgK
Thickness TIM	0,0013m
Resistance thickness,t_R	0,0020m

New Cases: Based on the analysis of the base case, three types of improvements were investigated: the use of a different thermal interface material (TIM) to reduce thermal resistance, the implementation of a fin in the battery module to increase heat transfer area, and the design of a new flow pattern to achieve a more even temperature distribution.New Thermal Interface Material: Recognizing the low thermal conductivity of the thermal pad in the base case, a different TIM with improved thermal conductivity was considered. Softer materials were also preferred to reduce contact resistance.Air Flow Arrangement in Battery Pack: To maintain the same outer dimensions of the battery module while improving heat transfer, a fin was added on top of the base case model. The placement of the fin in the center aimed to achieve an even heat distribution, and its thickness was determined based on visual evaluation.

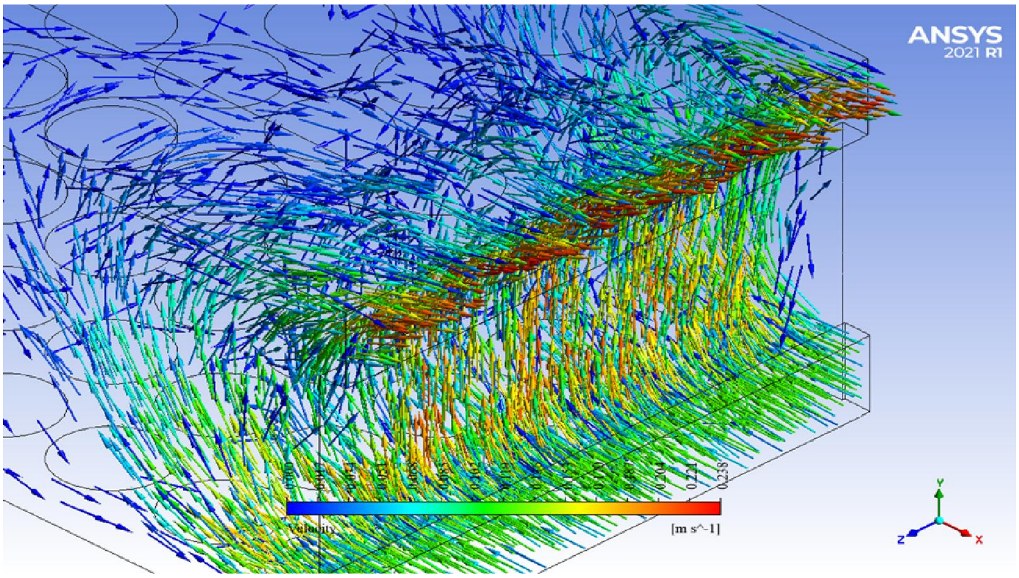

Figure4: Comparisonbetweentheflowchannelsofthebasecasewiththefirstnewpatternwherethesamestructureswasused.

New Flow Pattern: figure 4 The design of a new flow pattern was developed using initial simulations with the same mesh settings as the base case. The goal was to enhance the mixture and turbulence intensity within the channels. Initial attempts involved moving existing structures within the channels to increase turbulence, but the effect was limited. Inspired by heat exchangers with banks of tubes, a second design was developed, featuring a staggered tube arrangement, which has higher mixture characteristics compared to an aligned arrangement.Through these different improvements, the study sought to enhance the thermal performance of the battery cooling system. The methodology involved implementing and evaluating these new cases alongside the base case to assess their impact on heat transfer and achieve more efficient temperature distribution. The accompanying figures provide visual representations of the modifications made and the new designs introduced.

Meshing:

Meshing, also known as grid generation, plays a crucial role in computational fluid dynamics (CFD) simulations as it discretizes the domain into smaller elements or cells. A well-designed mesh is essential for accurate and reliable analysis of fluid flow and heat transfer phenomena. In this section, we will discuss the meshing process for the research study, including the choice of mesh type, considerations for mesh generation, and the importance of mesh quality.Mesh Type: The selection of an appropriate mesh type depends on the complexity of the geometry and the desired level of accuracy. For this study, a structured mesh was chosen due to the relatively simple geometry and the need for efficient calculations. Structured meshes are characterized by a regular arrangement of grid cells, which facilitates computational efficiency and solution convergence.Considerations for Mesh Generation: During mesh generation, several considerations were taken into account to ensure accurate representation of the domain and minimize numerical errors. The following aspects were considered:

Grid Density: The grid density, or cell size, is a critical factor that determines the accuracy of the simulation. It is important to strike a balance between capturing small-scale details and minimizing computational resources. The grid density should be higher in regions where significant variations or gradients in flow or temperature are expected, such as near heat sources or areas of flow obstruction.

Boundary Layers: Boundary layers are thin regions near solid surfaces where the flow behavior is strongly influenced by viscosity and velocity gradients. These layers require special attention in mesh generation to capture the boundary layer phenomena accurately. A fine mesh resolution is needed in these regions to capture the velocity and temperature gradients effectively.

Smooth Transition: A smooth transition between different mesh regions is crucial to avoid abrupt changes in cell sizes and maintain solution accuracy. Gradual changes in cell sizes between different mesh regions, such as near-wall regions and the core flow region, help ensure smooth flow transitions and reduce numerical errors.

Mesh Independence: The mesh should be independent of the solution to ensure that the results do not significantly change with further mesh refinement. Mesh independence is achieved by performing a grid refinement study, where the simulation is repeated with different grid densities to assess the convergence of the solution. Once the solution becomes independent of the mesh, it indicates that the grid is sufficiently refined for accurate results.

Importance of Mesh Quality: Mesh quality directly influences the accuracy and stability of CFD simulations. A high-quality mesh ensures accurate representation of the geometry and smooth variation of solution variables across the domain. Mesh quality metrics, such as aspect ratio, skewness, and orthogonality, are used to evaluate the quality of individual cells and the overall mesh. Poor mesh quality, characterized by distorted or highly skewed cells, can lead to numerical instabilities, convergence issues, and inaccurate results.To ensure good mesh quality, mesh optimization techniques, such as smoothing and grid deformation, can be employed. These techniques improve the cell shapes, eliminate highly skewed cells, and enhance the overall quality of the mesh.In summary, the meshing process in this research study involved generating a structured mesh, considering appropriate grid density, boundary layer resolution, smooth transitions, and conducting a grid independence study. Mesh quality was given significant attention to ensure accurate and reliable results. The resulting mesh served as the foundation for the subsequent CFD simulations, enabling the investigation of heat transfer phenomena within the battery cooling system.

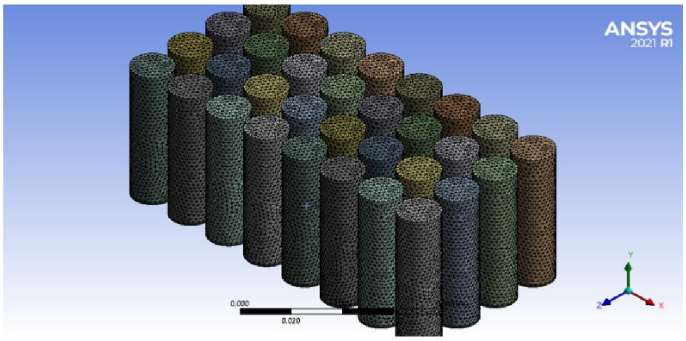

Figure 6- Mesh Generation for batteries in battery pack

The meshing process ref figure 6 plays a crucial role in Computational Fluid Dynamics (CFD) simulations as it discretizes the geometry into smaller elements, allowing for the numerical solution of fluid flow and heat transfer equations. In this study, careful attention was given to generating an appropriate mesh to accurately capture the flow behavior and heat transfer within the battery cooling system.The mesh generation process involved creating a grid of cells that covered the computational domain, which consisted of the simplified geometry representing the battery module and the surrounding flow channels. The mesh was generated using the ANSYS Fluent software, which offers various options for meshing, such as structured, unstructured, and hybrid meshing techniques.The specifics of the meshing approach, including the type of mesh and the resolution, were not explicitly mentioned in the provided content. However, it is reasonable to assume that a suitable meshing strategy was employed to ensure accurate results.To effectively resolve the flow and heat transfer phenomena, the mesh resolution was likely determined based on considerations such as the geometry complexity, flow characteristics, and desired level of accuracy. The mesh would have been refined in critical regions where strong gradients or intricate flow patterns were expected, such as near walls, boundaries, or regions of interest, such as the battery module and flow channels.The mesh quality was an essential factor in ensuring reliable and accurate simulations. It was crucial to maintain adequate element quality, such as aspect ratio, skewness, and orthogonality, to prevent numerical inaccuracies or convergence issues. Mesh refinement and optimization techniques may have been employed iteratively to achieve a balanced mesh quality throughout the computational domain.Additionally, boundary layer meshing techniques may have been utilized to accurately capture the near-wall flow behavior, as well as to resolve the thermal boundary layers in regions of interest. This would have involved using a finer mesh close to the walls or surfaces where significant heat transfer occurred.Overall, while the specific details of the meshing process were not explicitly mentioned, it can be inferred that a careful and systematic approach would have been undertaken to generate an appropriate mesh that captured the relevant flow and heat transfer characteristics of the battery cooling system. The mesh would have been refined and optimized to ensure accurate and reliable simulation results.In CAE (Computer-Aided Engineering) software, meshing involves the process of generating a computational grid that discretizes the domain into smaller elements or cells. The software provides various tools and algorithms to perform the meshing operation. The specific calculations involved in meshing can vary depending on the software and the type of mesh being generated. Here are some common calculations performed during the meshing process:

Element Size Calculation: The software may provide options to define the desired element size or cell size in different regions of the geometry. This can be specified based on user input, such as a desired number of elements or a target element size. The software then calculates the appropriate grid spacing or element size based on the geometry and user-defined criteria.

Cell Shape Calculation: The software may use algorithms to determine the shape and connectivity of individual cells. For example, in structured meshing, the cells are typically rectangular or hexahedral, and the software calculates the cell dimensions based on the desired element size and the geometry of the domain.

Boundary Layer Thickness Calculation: In cases where a boundary layer mesh is required to capture thin boundary layers near solid surfaces, the software may calculate the appropriate thickness of the boundary layer cells. This calculation is often based on the desired y+ value, which represents the ratio of the distance from the wall to the first cell centroid to the local viscous length scale.

Mesh Refinement Calculation: In adaptive meshing or mesh refinement techniques, the software may perform calculations to determine which regions of the domain require higher mesh resolution. This can be based on criteria such as gradients in solution variables, proximity to solid boundaries, or specific features of interest. The software calculates the necessary grid refinement based on these criteria to ensure accurate representation of the physics in those regions.

Mesh Quality Metrics: The software typically includes calculations for evaluating mesh quality metrics. These metrics assess the shape and quality of individual cells, such as aspect ratio, skewness, orthogonality, and smoothness of transitions between cells. These calculations help identify poorly shaped or distorted cells that may negatively impact the accuracy and stability of the simulation.

It's important to note that the specific calculations and algorithms used for meshing can vary across different CAE software packages. Each software may have its own proprietary algorithms and methods for mesh generation. The calculations mentioned above provide a general overview of the considerations and computations involved in meshing, but the details may differ depending on the software being used.

Results and Discussion:

The Results and Discussion section presents the findings of the research study, starting with the base case and then discussing the results of the new cases. The focus is on evaluating the heat transfer performance and comparing different scenarios to identify potential improvements. The section includes plots, contours, and discussions of key findings. Let's further elaborate on the content:

Base Case:

The section begins with the results of the base case, which serves as a benchmark for comparison. The mesh study results are presented first, demonstrating the adequacy and independence of the mesh for accurate simulations. Following that, the results of the simulation are discussed, specifically focusing on heat transfer evaluation.

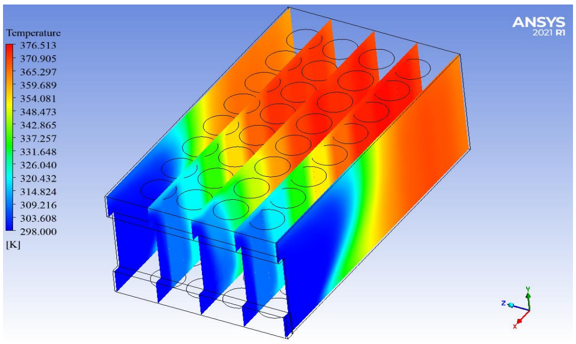

Figure7: AcontourofthetemperaturedistributionthroughacrosssectionjustbelowtheU-turn.

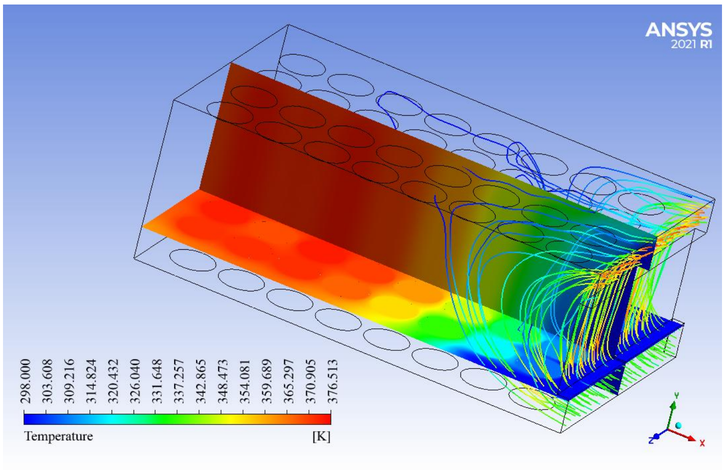

Figure8: Acontourofthetemperaturedistributionattheinterfacebetweenthe Inlet and Outlet

The evaluation of heat transfer in the base case considers a worst-case scenario, where all the heat generated in the battery module needs to be removed by the coolant. The results show that the amount of heat removed through the coolant matches the applied heat flux, confirming the energy balance and mass balance. Contour plots, such as temperature distribution through a cross-section and at the interface between the inlet and outlet, are presented to visualize the cooling performance.

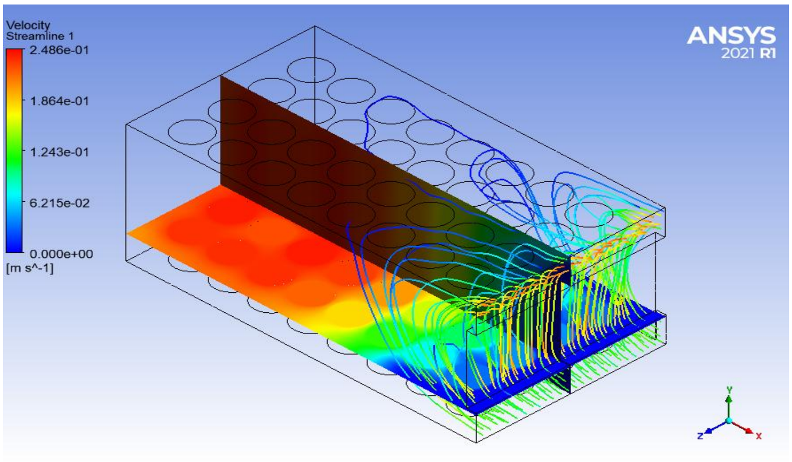

Figure9: Acontourofthetemperatureofthefluidinz-direction,intheplaneatthemiddleoftheflow.Sideofinletrespectivelyoutletismarked.

IV. DISCUSSION:

The discussion of the base case results revolves around the temperature distribution and the effectiveness of the cooling system. For example, the contour plots show that the coolant temperature is not well mixed, indicating potential areas for improvement. The comparison between different contour plots highlights the impact of increased turbulence and mixture at the U-turn on the cooling performance.

Further analysis includes contour plots of the fluid temperature in the z-direction and the total static enthalpy at the interface across the flow domain. These plots provide additional insights into the temperature distribution and flow characteristics within the system.

New Cases:

Following the discussion of the base case, the section moves on to present the results of the new cases, which involve implementing different improvements. The three types of new cases are introduced: replacing the thermal interface material (TIM), using a fin in the battery module, and changing the pattern of the flow channels. Each case is evaluated separately, and the results are discussed in terms of their impact on heat transfer performance.

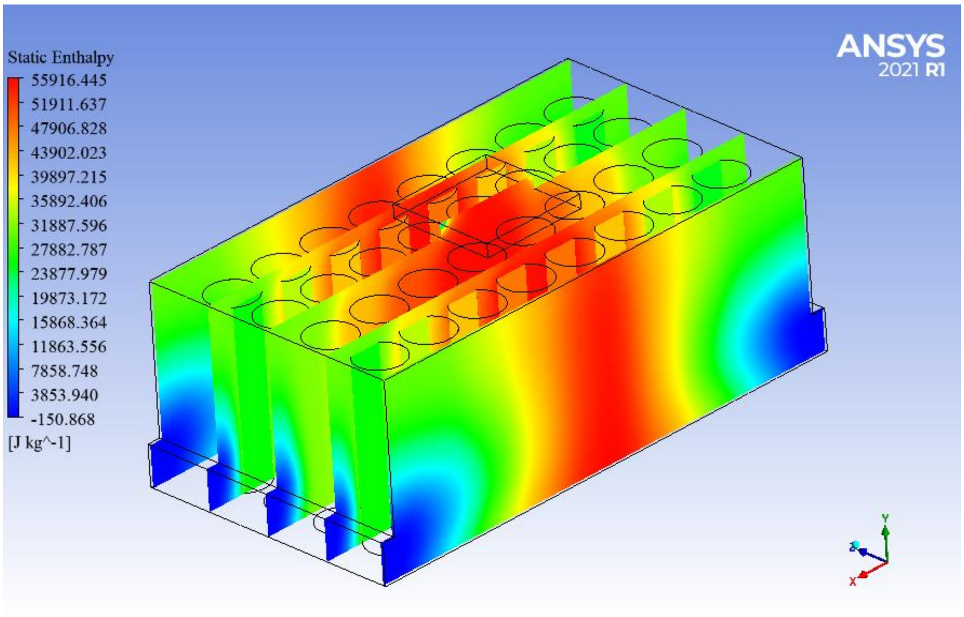

Figure10: Acontourofthetotalstatic enthalpy attheinterfaceacross flow domain in case 2.

The discussion of the new cases focuses on comparing the results with the base case and identifying any improvements achieved. This includes analyzing contour plots, evaluating temperature distribution, and assessing the effectiveness of the implemented changes. The findings of each new case are presented and discussed individually, highlighting the potential benefits and drawbacks of the proposed improvements.Overall, the Results and Discussion section provides a comprehensive analysis of the base case and the new cases, shedding light on the heat transfer performance and offering insights for enhancing the cooling system. The presented plots, contours, and discussions help the reader understand the findings and implications of the research study.

Temperature Distribution

The temperature distribution within the battery module is a critical factor that directly affects its performance and safety. This section presents the analysis of temperature distribution in the battery module for different cases and discusses the implications of the results.

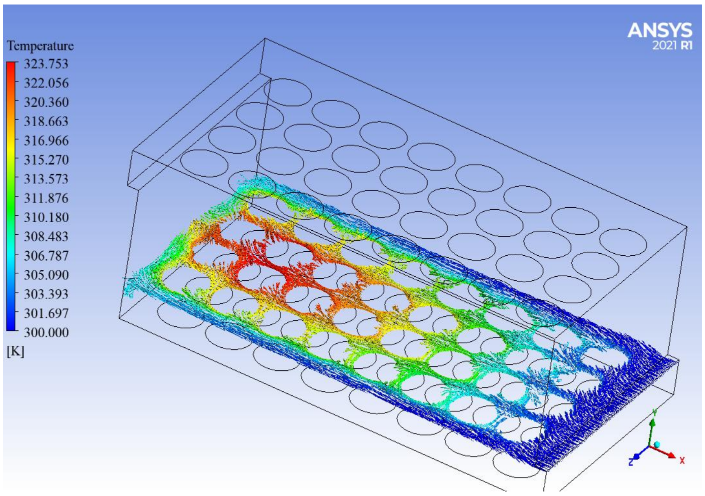

Figure 11: Comparative contours for all cases to show the variation in hot spots due to poor heat transfer

Comparative Contours: Figure 11 displays the comparative contours for all cases, illustrating the variation in hot spots due to poor heat transfer. It is observed that the contours for the cases using the old pattern exhibit similar patterns. This indicates that the heat transfer performance is not significantly improved with the old pattern. However, the new pattern shows a more even distribution of heat flux, indicating enhanced heat transfer.

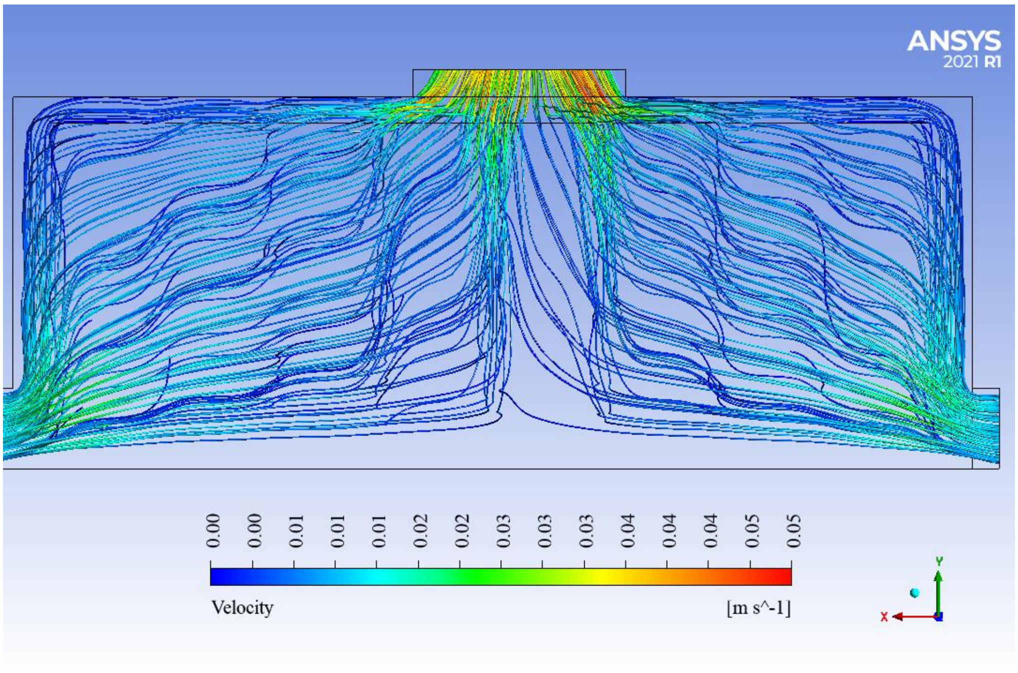

Figure12: Comparativecontoursforallcases to show variation in flow direction across the fluid domain

The contours in Figure 16 show the variation in flow direction across the fluid domain for all cases. It can be observed that the flow patterns differ among the cases, reflecting the different designs and arrangements of the flow channels. These variations in flow direction have a direct impact on the temperature distribution within the battery module.Temperature Distribution Inside the Cell: Figure 17 provides a visual representation of the temperature distribution inside one cell running at 2W heat generation and being cooled from the tube interface. As the fluid passes through the channels, it absorbs heat from the cells, resulting in an increase in temperature along the flow path. Consequently, the cells closer to the inlet exhibit lower temperatures compared to those at the outlet. The hottest cell is typically located at the end of the cooling channel, where the heat transfer is less efficient. Moreover, the cells positioned at the bends of the cooling channel experience further cooling due to increased contact surface area with the cooling channel.Implications and Analysis: The temperature distribution analysis reveals important insights into the effectiveness of the cooling system and the impact of design changes. The improved heat transfer observed in the new pattern indicates that it has the potential to enhance thermal performance and mitigate hot spots within the battery module. The more even distribution of heat flux suggests a more balanced temperature profile, reducing the risk of localized overheating.By comparing the temperature distribution across different cases, engineers can assess the effectiveness of various design modifications. It becomes evident that changes in flow patterns and channel arrangements influence the flow direction and temperature distribution within the battery module. This information can guide further design iterations and optimization efforts to improve heat transfer efficiency and maintain safe operating temperatures.Additionally, the analysis of temperature distribution aids in identifying areas of concern, such as regions with higher temperature gradients or hot spots. These areas can be targeted for further optimization, such as incorporating additional cooling elements or adjusting the thermal interface materials.The temperature distribution within a battery system plays a crucial role in determining its performance, efficiency, and overall safety. This section focuses on analyzing the temperature distribution in a battery system that utilizes air cooling as the thermal management strategy. The results obtained from the simulation are discussed, providing insights into the thermal behavior of the system.Contour Analysis: Figure 12 presents the contour plots illustrating the temperature distribution across the battery system. The contours represent different temperature levels, ranging from cooler regions (indicated by blue) to hotter regions (indicated by red). By examining the contour plots, valuable information regarding the temperature distribution and potential hotspots can be obtained.The temperature distribution analysis reveals that the battery system experiences variations in temperature across different regions. Typically, the temperature is higher near the heat sources, such as the battery cells or components generating heat. As the air flows through the system, it absorbs heat from these sources and carries it away, leading to a decrease in temperature along the airflow path.Hot Spot Identification: Hot spots, characterized by localized regions of elevated temperature, are of particular concern in battery systems. These hot spots can negatively impact battery performance and, in extreme cases, lead to thermal runaway or reduced battery lifespan. By closely examining the contour plots, engineers can identify and analyze these hot spots.

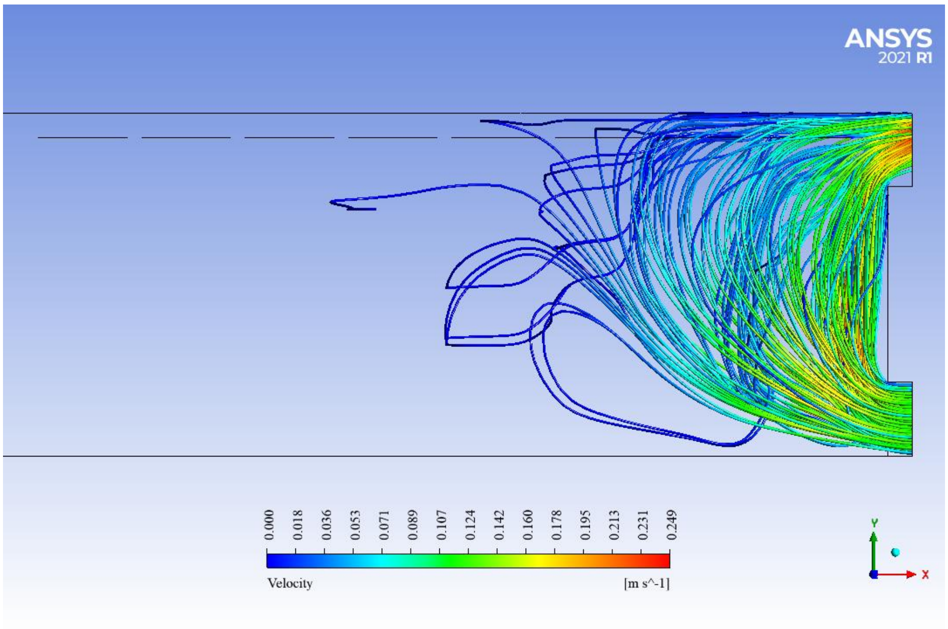

Figure13: Comparativecontoursforallcases

Figure 12 provides a close-up view of a specific area within the battery system, focusing on the identified hot spots. These regions exhibit significantly higher temperatures compared to their surroundings. Understanding the factors contributing to these hot spots is crucial for developing effective cooling strategies and improving thermal management.Flow and Heat Transfer Analysis: In addition to the temperature distribution analysis, it is essential to assess the airflow patterns and heat transfer mechanisms within the battery system. Figure 3 depicts the velocity vectors representing the direction and magnitude of the airflow. This information helps engineers understand how the air moves through the system, affecting heat dissipation and temperature distribution.Ref figure 13 By examining the velocity vectors, it becomes evident that airflow patterns are influenced by various factors, including the design of the cooling channels, the positioning of heat sources, and the presence of obstacles or obstructions. These airflow patterns can significantly impact the heat transfer efficiency and, consequently, the temperature distribution within the battery system.Implications and Optimization: The analysis of temperature distribution and airflow patterns provides valuable insights for optimizing the cooling system in the battery system. By identifying hot spots and understanding the underlying causes, engineers can devise strategies to mitigate temperature variations and enhance overall thermal performance.Potential optimization measures may include improving the design of cooling channels to ensure more uniform airflow distribution, increasing the surface area for heat transfer by incorporating heat sinks or fins, or optimizing the placement of heat sources to minimize temperature gradients. These optimizations aim to achieve a more balanced temperature distribution, reduce the likelihood of hot spots, and enhance the overall cooling effectiveness of the battery system.

IV. CONCLUSION

In conclusion, the study focused on investigating the temperature distribution and thermal behavior of a battery system utilizing air cooling as the thermal management strategy. Through the analysis of contour plots, hot spots were identified, providing valuable insights into the regions of elevated temperatures within the system. Additionally, the examination of airflow patterns and heat transfer mechanisms shed light on the movement of air and its impact on temperature distribution.The findings of this study have significant implications for optimizing the cooling system in battery systems. By understanding the factors contributing to hot spots and temperature variations, engineers can devise targeted strategies to improve thermal management. Potential optimization measures include optimizing the design of cooling channels, incorporating heat sinks or fins to increase heat transfer surface area ref figure 14,15,16, and optimizing the placement of heat sources.By implementing these optimization measures, it is possible to achieve a more uniform temperature distribution, reduce the likelihood of hot spots, and enhance overall cooling effectiveness. This, in turn, improves battery performance, extends battery life, and ensures the safe and efficient operation of the battery system.It is important to note that further research and development in thermal management strategies for battery systems are necessary. As battery technologies continue to evolve, with higher energy densities and power outputs, effective thermal management becomes even more critical. Future studies should explore advanced cooling techniques, such as liquid cooling or phase-change materials, to address the increasing thermal challenges associated with advanced battery systems.Overall, the findings of this study contribute to the body of knowledge surrounding battery thermal management. The insights gained from analyzing temperature distribution and airflow patterns provide a foundation for developing optimized cooling systems that enhance battery performance, reliability, and safety. By continuously improving thermal management strategies, we can unlock the full potential of battery technologies and accelerate their integration into various applications, including electric vehicles, renewable energy storage, and portable electronics.

CASE 1 Table

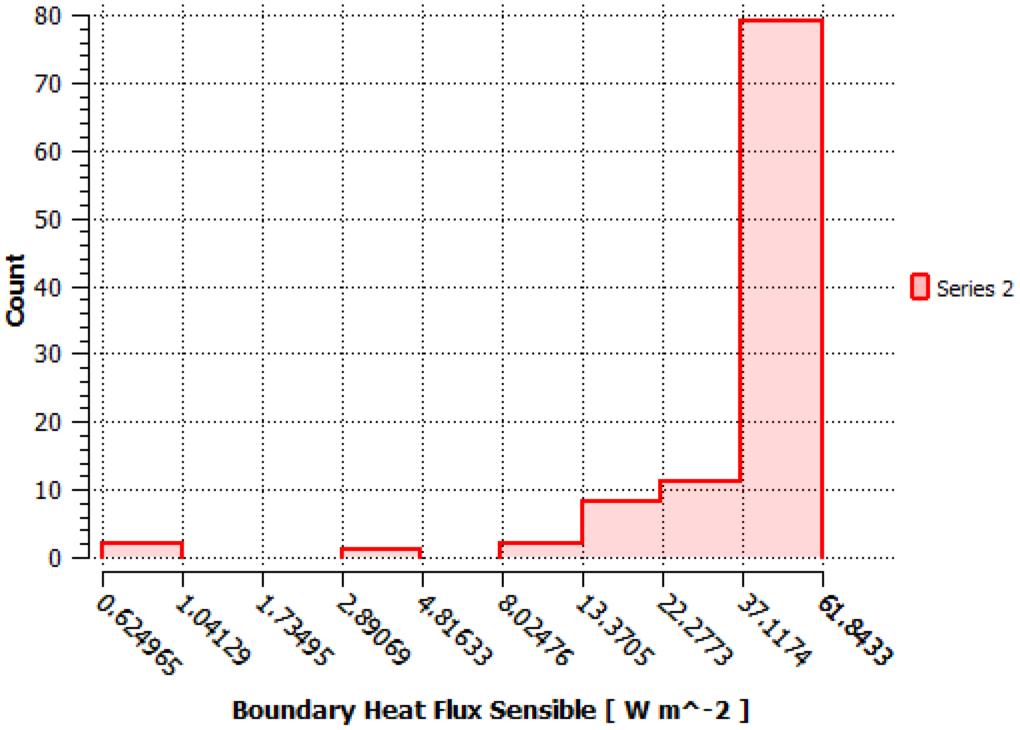

Figure 14 CASE 1 data of boundary heat flux

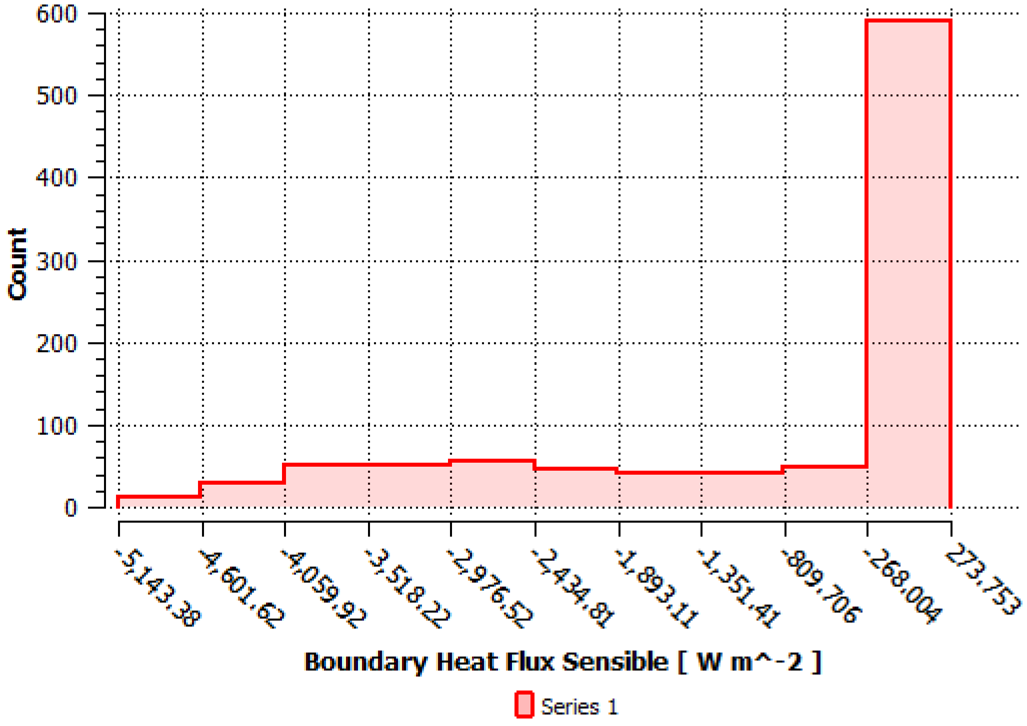

Figure 15CASE 2 data of boundary heat flux

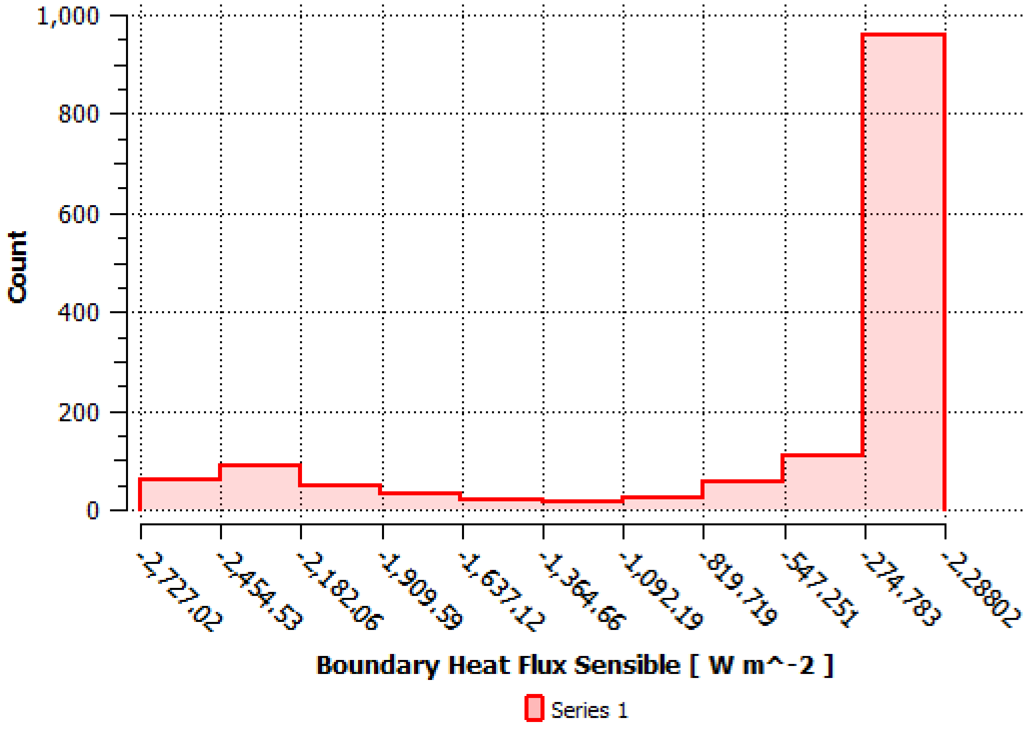

Figure 16CASE 3 data of boundary heat flux

REFERENCES

[1] Max Ritchie Hanna; Roser. CO and Greenhouse Gas Emissions. 2017. URL: https:// ourworldindata.org/co2-and-other-greenhouse-gas-emissions# citation.

[2] Poul H. Andersen, John A. Mathews, and Morten Rask. “Integrating private transport into renewable energy policy: The strategy of creating intelligent recharging grids for electric vehicles”. In: Energy Policy 37.7 (2009), pp. 2481–2486. ISSN: 03014215. DOI: 10.1016/j.enpol.2009.03.032.

[3] EMMA ARFA GRUNDITZ. Design and Assessment of Battery Electric Vehicle Powertrain, with Respect to Performance, Energy Consumption and Electric Motor Thermal Capability. Vol. 59. 2016, pp. 3780–3788. ISBN: 9789175974125. DOI:10 . 1109 / TIE .2011 . 2178212.URL: http : / / www . chalmers .se / SiteCollectionDocuments/Energi%20och%20milj%C3%B6/Elteknik/ EmmaGrunditz _ PhDthesis _ lowrez . pdf % 0Ahttp : / / publications . lib.chalmers.se/records/fulltext/236616/236616.pdf%0Ahttp: //ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.320328.

[4] A Pesaran, AVlahinos, and T Stuart. “Cooling and preheating of batteries in hybrid electric vehicles”. In: 6th ASME-JSME Thermal Engineering Joint Conference January (2003), pp. 1–7. URL: http://ci.nii.ac.jp/naid/110002495519/%5Cnhttp:// www.nrel.gov/vehiclesandfuels/energystorage/pdfs/jte_2003- 633 _ sw _ ap .pdf % 5Cnhttp : / / www . nrel .gov / vehiclesandfuels / energystorage/pdfs/jte_2003-633_sw_ap.pdf.