iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** VIII **Month of publication:** August 2025

DOI: https://doi.org/10.22214/ijraset.2025.73570

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

CFD-Based Performance Evaluation of Microchannel Cooling for Electric Vehicle Battery Packs

Ankur Sahu[1], Aseem C Tiwari[2], Arvind Kumar Namdev[3]
[1]*Research Scholar, Department of Mechanical Engineering, University Institute of Technology, RGPV, Bhopal, India*
[2]*Professor, Department of Mechanical Engineering, University Institute of Technology, RGPV, Bhopal, India*
[3]*Assistant Professor (Contract), Department of Mechanical Engineering, University Institute of Technology, RGPV, Bhopal, India*

Abstract: This study presents a computational analysis of a microchannel-based liquid cooling system for cylindrical lithium-ion battery packs in electric vehicles (EVs), using ANSYS Fluent. The investigation compares water and ethylene glycol as coolants under high-load conditions, with simulations focusing on temperature distribution, wall heat flux, flow velocity, and pressure drop. Ethylene glycol achieved better thermal performance with a 42°C temperature drop and peak wall heat flux of 0.5518 W/m² but suffered from a high pressure drop (~1557.2 Pa) due to its higher viscosity. Water provided a more balanced solution, offering a 28°C temperature drop, lower pressure loss (~741.4 Pa), and superior flow uniformity, making it more practical for standard EV applications. The study underscores the trade-off between cooling efficiency and hydraulic resistance and recommends future research involving nanofluids, transient simulations, and AI-driven thermal management strategies to further enhance BTMS performance.
Keywords: Battery Thermal Management, Microchannel Cooling, CFD, Electric Vehicles, ANSYS Fluent, Coolant Comparison

I. INTRODUCTION

The global transition toward cleaner, more sustainable transportation has positioned electric vehicles (EVs) at the forefront of innovation in the automotive industry. Unlike conventional internal combustion engine (ICE) vehicles, EVs operate using electric propulsion powered by onboard batteries, typically lithium-ion (Li-ion) chemistry, which offer higher energy density, long cycle life, and favorable power-to-weight ratios (Nykvist & Nilsson, 2015). With the rapid adoption of EVs, driven by regulatory pressure, environmental concerns, and consumer demand, the technological focus has shifted toward optimizing core systems—especially the battery packs, which play a central role in determining vehicle performance, range, safety, and reliability (International Energy Agency, 2022). However, Li-ion batteries are highly sensitive to temperature fluctuations, requiring sophisticated thermal regulation to operate efficiently and safely across a wide range of ambient and load conditions.

The optimal operating temperature for most Li-ion batteries lies between 20°C and 40°C. Deviations beyond this window can result in performance degradation, capacity fade, and, in extreme cases, thermal runaway—a self-propagating exothermic reaction that may lead to combustion or explosion (Wang et al., 2012). High temperatures accelerate side reactions in the cell, reduce electrolyte stability, and exacerbate aging, whereas low temperatures increase internal resistance and reduce charge acceptance, particularly during fast charging. These challenges have spurred the development of Battery Thermal Management Systems (BTMS), which are engineered to maintain the battery temperature within a narrow, optimal band while ensuring uniform distribution across all cells in the pack (Pesaran, 2001). A well-functioning BTMS not only enhances battery safety and longevity but also improves energy efficiency and enables the use of advanced charging protocols without compromising battery health.

Historically, air cooling and indirect liquid cooling have been the primary methods used in BTMS implementations. Air cooling, either passive or active using fans, is relatively simple and inexpensive but suffers from poor heat transfer efficiency and limited scalability, especially for high-energy-density battery configurations (Neubauer & Wood, 2014). Liquid cooling, on the other hand, typically involves circulating water or a glycol-based solution through cooling plates adjacent to the cells. While it offers better heat transfer characteristics, traditional liquid cooling can introduce uneven temperature distribution and is constrained by packaging limitations in compact vehicle architectures (Chen et al., 2011). As EVs demand increasingly compact, high-capacity battery modules—especially in performance models and fast-charging applications—there is a growing need for more advanced, high-efficiency thermal management solutions.

In recent years, microchannel cooling has emerged as a promising candidate to meet the evolving thermal management needs of EVs. Microchannel heat exchangers, characterized by channel diameters typically in the range of 100–500 micrometers, offer an exceptionally high surface area-to-volume ratio, enabling efficient heat transfer in confined spaces (Fan et al., 2017). These systems allow for the coolant to flow directly beneath or between battery cells, ensuring localized and responsive heat removal. Compared to conventional cooling strategies, microchannel systems deliver superior thermal gradients, faster heat extraction, and better temperature uniformity. Their compact design is especially advantageous in modern EV layouts, where maximizing space utilization is crucial. Moreover, with appropriate design, microchannel plates can be integrated directly into the battery pack's structure, eliminating the need for external heat exchangers or complex manifolds (Hadad et al., 2015).

Despite these advantages, the practical implementation of microchannel cooling in EVs poses several technical and operational challenges. The small channel dimensions necessitate high-precision manufacturing, often involving laser micromachining, photochemical etching, or advanced additive manufacturing techniques (Prakash et al., 2014). These processes can increase production complexity and cost. Additionally, microchannel systems are more prone to clogging and fouling due to their narrow geometry, requiring strict fluid quality control and potentially more maintenance. Hydraulic performance is another critical concern; while tighter channels enhance heat transfer, they also increase pressure drop, leading to higher pumping power requirements and potential system inefficiency (Islam et al., 2018). Therefore, a comprehensive understanding of fluid dynamics, material behavior, and heat transfer characteristics is essential when designing a microchannel-based BTMS for practical automotive applications.

Among the key considerations in such systems is the choice of coolant fluid. Water, with its high specific heat capacity (4182 J/kg·K) and thermal conductivity (0.60 W/m·K), is widely regarded as one of the most effective heat transfer media. It is readily available, inexpensive, and non-toxic. However, it has limitations such as a relatively low boiling point (100°C at atmospheric pressure) and the risk of freezing in cold climates. Ethylene glycol, a commonly used coolant in automotive applications, addresses some of these issues with its higher boiling point and lower freezing temperature. Nevertheless, it is significantly more viscous (16 mPa·s compared to water's 0.89 mPa·s), has lower specific heat and thermal conductivity, and presents a higher pressure drop in microchannel systems, thereby increasing energy consumption and component wear (Li et al., 2021). The trade-offs between thermal efficiency, hydraulic performance, and environmental conditions make coolant selection a critical aspect of BTMS design.

Computational Fluid Dynamics (CFD) has become an indispensable tool in evaluating and optimizing BTMS architectures. CFD simulations allow engineers to predict the flow behavior, temperature distribution, and pressure profiles within complex geometries under various loading and boundary conditions, without the need for expensive and time-consuming physical prototyping (Harpol et al., 2010). In the context of microchannel BTMS, CFD enables detailed investigation of how different channel shapes, layouts, and coolant properties influence thermal and hydraulic performance. Several studies have applied CFD to explore novel configurations and enhance microchannel designs, including serpentine, trapezoidal, and stepped channel structures, as well as hybrid systems incorporating phase change materials (PCMs) or nanofluids for added thermal capacity (Sharma et al., 2023; Kim et al., 2023).

This paper aims to contribute to the field by presenting a detailed CFD-based study of a microchannel cooling system integrated into a 10s4p cylindrical Li-ion battery module, representative of those used in modern electric vehicles. The analysis focuses on comparing the performance of water and ethylene glycol as coolants under steady-state high-load conditions. Metrics such as temperature distribution, wall heat flux, and pressure drop are evaluated to assess the effectiveness and trade-offs associated with each fluid. By analyzing the thermal and hydraulic performance of these fluids within a practical microchannel geometry, the study provides insights into coolant selection and system optimization for advanced EV BTMS applications. Ultimately, the findings help inform the design of more reliable, energy-efficient, and high-performance cooling strategies aligned with the evolving demands of electric mobility.

II. METHODOLOGY

A. System Design

The battery module analyzed in this study was modeled as a 10s4p configuration, meaning 10 cells in series and 4 in parallel, totaling 40 cylindrical lithium-ion cells. Each cell was designed with dimensions of 26 mm in diameter and 65 mm in height, approximating the commercial 21700 format with slight modifications. These cells were arranged in a rectangular layout with consistent contact on a common cooling base. To facilitate effective heat dissipation, a serpentine microchannel plate was integrated directly beneath the battery array. This design allows the coolant to pass directly beneath each cell row, ensuring uniform contact with heat-generating surfaces. The serpentine layout was chosen for its compact footprint and long fluid path, which maximizes surface area and promotes thermal uniformity. This setup was modeled using CAD tools and prepared for fluid analysis to simulate real-world heat dissipation patterns and thermal interaction within a constrained EV battery pack enclosure.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

The 3D structure of the battery module with its wave-shaped microchannel cooling layout is illustrated in Figure 1, showing optimized coolant paths aligned with the cell array for efficient thermal management.

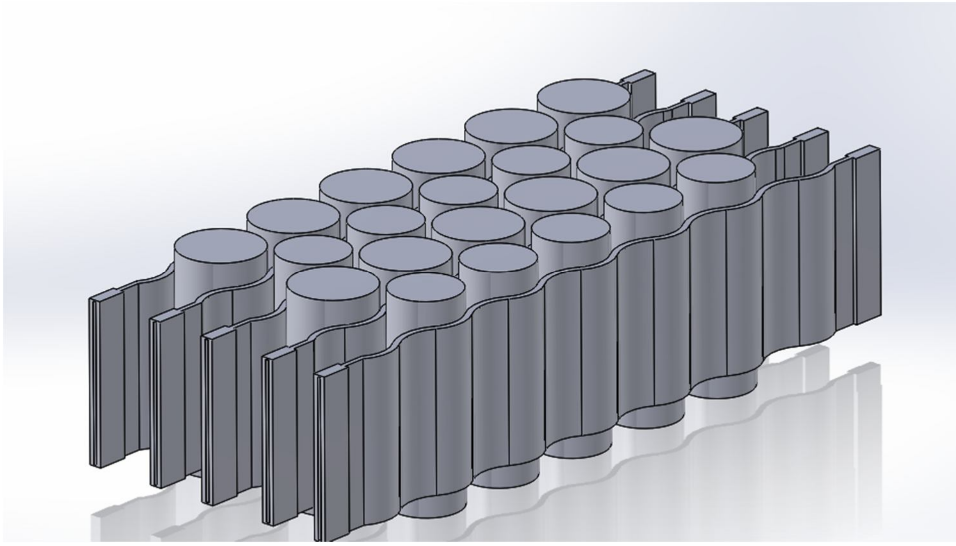


Figure 1. Battery Pack Model with Integrated Microchannels

B. CFD Simulation

Computational Fluid Dynamics (CFD) analysis was carried out using ANSYS Fluent under steady-state conditions to evaluate coolant flow and heat transfer behavior within the microchannel system. Two coolants—water and ethylene glycol—were studied to compare their effectiveness under identical thermal loading. Input parameters for the simulation included an inlet fluid velocity of 2.0 m/s and an inlet temperature of 22°C. A constant thermal load was applied at the base of the battery cells, simulating a maximum operating temperature of 60°C. A structured hexahedral mesh with approximately 1.2 million elements was used to capture near-wall gradients and flow details accurately. The pressure-based solver with the standard k–ε turbulence model was selected to handle low-speed, incompressible flow with modest turbulence. The energy equation was activated to track temperature distribution throughout the system. Second-order upwind discretization schemes were employed for all governing equations to improve accuracy, and convergence was achieved when residuals fell below 10^{-3} for flow variables and 10^{-6} for energy. This setup enabled detailed analysis of pressure drop, velocity profiles, and thermal gradients for both coolants under controlled and replicable conditions.

III. RESULTS AND DISCUSSION

This section presents the results of the CFD simulation, comparing the thermal and hydraulic performance of water and ethylene glycol as coolant fluids in a microchannel-based Battery Thermal Management System (BTMS) under identical boundary conditions. The analysis is structured into three key performance categories: coolant properties, thermal performance, and pressure behavior.

A. Coolant Properties

The thermophysical properties of the two coolants—water and ethylene glycol—were defined at a reference temperature of 25°C and are summarized in Table 1. These properties directly influence both the heat transfer effectiveness and the flow characteristics within the microchannel cooling system.

Water exhibits a significantly higher thermal conductivity and specific heat capacity compared to ethylene glycol. These characteristics make water a superior medium for absorbing and transporting heat uniformly throughout the microchannel network. Ethylene glycol, although it has a higher boiling point and freeze protection, suffers from high dynamic viscosity and lower thermal properties. The much higher viscosity (~18 times that of water) introduces greater resistance to flow, which is expected to impact the hydraulic performance and pressure drop, as analyzed in Section 3.3.

Table 1: Coolant Properties at 25°C

Property	Water	Ethylene Glycol
Density (kg/m³)	997	1110
Specific Heat (J/kg·K)	4182	2415
Thermal Conductivity (W/m·K)	0.60	0.25
Viscosity (mPa·s)	0.89	16

B. Thermal Performance

The thermal behavior of the battery pack during coolant circulation is a crucial parameter in evaluating the effectiveness of the BTMS. Table 2 presents the key thermal results from the simulations for both water and ethylene glycol under a fixed inlet velocity (2.0 m/s), inlet temperature (22°C), and a peak surface temperature of 60°C representing the heat load.

Water-cooled simulation results show a minimum cell surface temperature of 32°C, resulting in a temperature drop of 28°C across the battery pack. In contrast, ethylene glycol achieved a more aggressive cooling effect, bringing temperatures down to 18°C—a drop of 42°C. While this indicates stronger heat extraction capabilities, it also introduces the risk of overcooling near the channel inlet, potentially leading to thermal stress or uneven cell aging over time.

These observations are visualized in Figure 2 and Figure 3, which show the temperature distribution across the battery base plate for each coolant. In Figure 2, the water-cooled case displays a smooth, uniform temperature gradient with minimal hotspots or cold zones. In Figure 3, the ethylene glycol case reveals sharper thermal gradients and signs of localized cooling zones near the inlet region, which may be undesirable in long-term battery health.

Table 2: Simulation Output Summary

Parameter	Water	Ethylene Glycol
Min Battery Temp (°C)	32	18
Max Battery Temp (°C)	60	60
Temp Drop (°C)	28	42
Wall Heat Flux (W/m²)	0.2267	0.5518

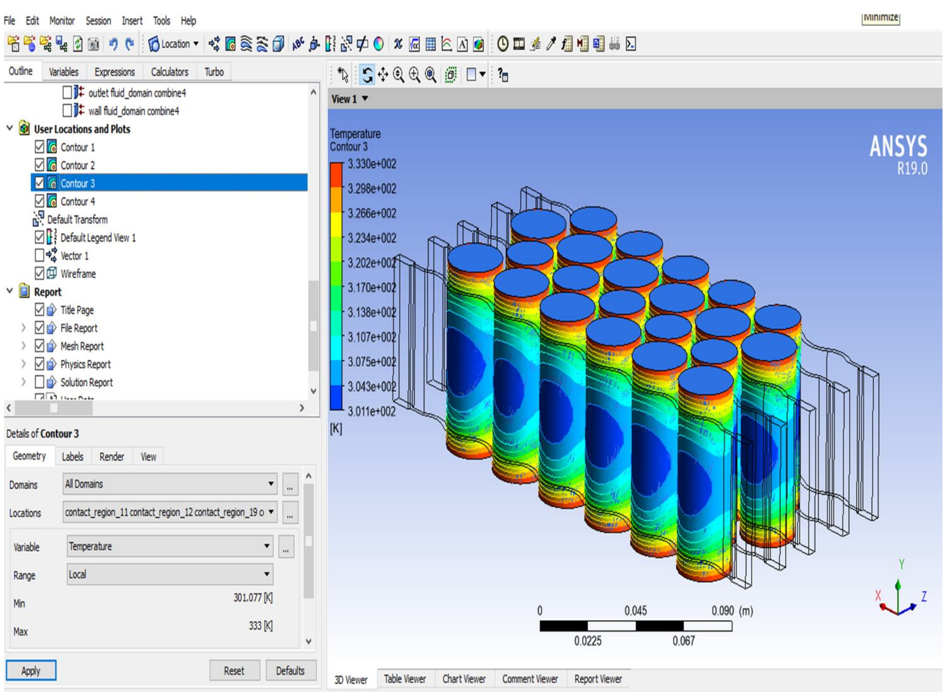


Figure 2: Temperature Distribution (Water)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue VIII Aug 2025- Available at www.ijraset.com

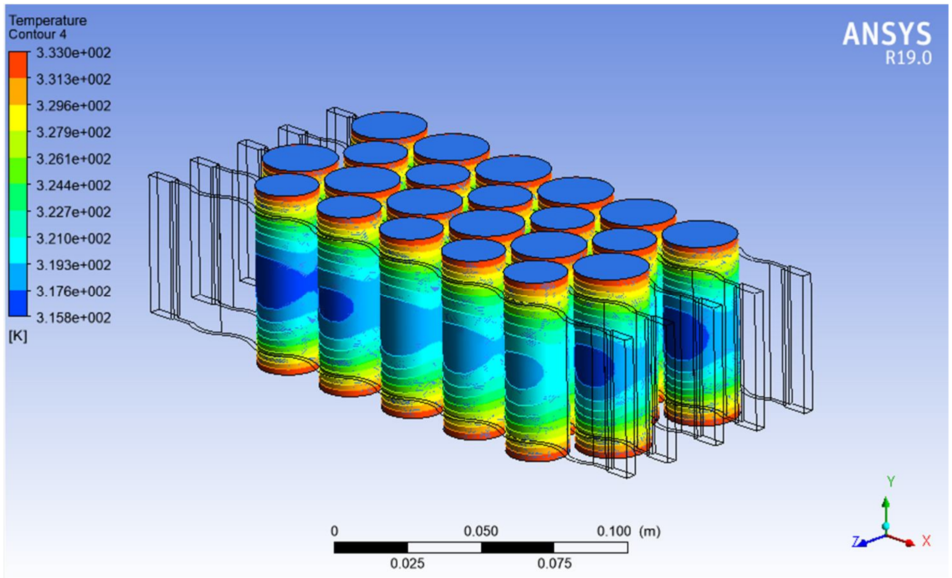


Figure 3: Temperature Distribution (Ethylene Glycol)

C. Pressure Behavior

The evaluation of pressure drop across the microchannel domain is essential to determine the coolant's hydraulic efficiency and the corresponding pumping power requirements. The pressure values at the inlet and outlet boundaries for both fluids are presented in Table 3. Water demonstrates a relatively low pressure drop (~741.4 Pa), indicative of stable and laminar flow within the microchannels. This low resistance implies reduced pumping requirements and greater system efficiency. In contrast, ethylene glycol—owing to its high viscosity—exhibits a pressure drop of ~1557.2 Pa, which is more than double that of water. This increased resistance can lead to higher energy consumption, more robust pump requirements, and possible long-term strain on system components. Figure 4 further illustrates the pressure distribution across the domain for both coolants. The water-cooled system maintains a gentle, evenly distributed pressure gradient, while the ethylene glycol case shows steeper gradients and higher inlet pressures, particularly near turns and constricted segments of the microchannel path.

Table 3: Pressure Drop Analysis

Parameter	Water	Ethylene Glycol
Inlet Pressure (Pa)	15041.4	31057.2
Outlet Pressure (Pa)	~14300	~29500
Pressure Drop (Pa)	~741.4	~1557.2

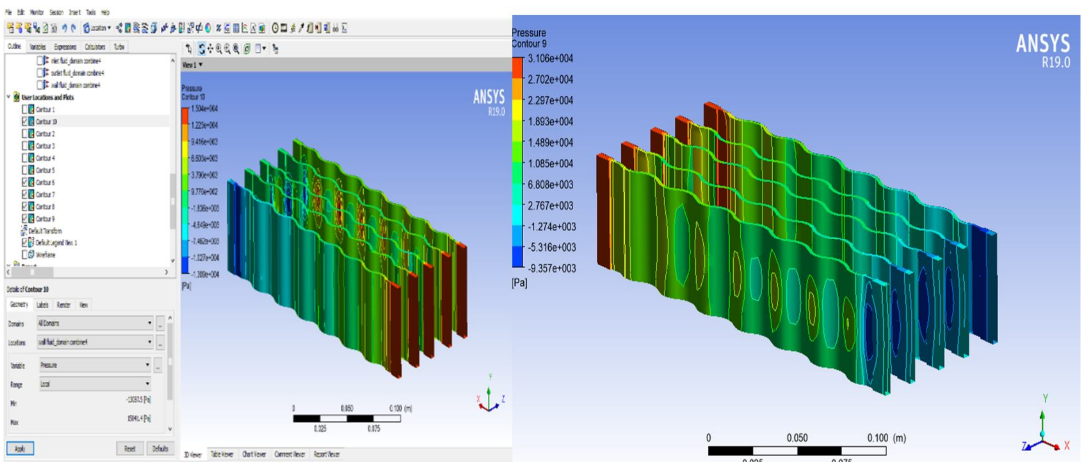


Figure 4: Pressure Drop Comparison

IV. COMPARATIVE ANALYSIS

The comparative evaluation of water and ethylene glycol as coolant fluids reveals distinct performance trade-offs that are critical in the design of Battery Thermal Management Systems (BTMS) for electric vehicles. Water demonstrates superior thermal uniformity due to its high specific heat capacity and thermal conductivity, resulting in more consistent temperature distribution across the battery module. This is evident from the smoother temperature gradient observed in simulation results and the lower wall heat flux value (0.2267 W/m²), indicating controlled and uniform heat absorption. Furthermore, water's lower viscosity (0.89 mPa·s) leads to a significantly lower pressure drop (~741.4 Pa), minimizing the energy required for pumping and thereby enhancing overall system efficiency. In contrast, ethylene glycol, while achieving a higher wall heat flux (0.5518 W/m²) and a greater temperature drop (42°C), incurs a higher pressure drop (~1557.2 Pa) due to its high viscosity (16 mPa·s). This implies increased hydraulic resistance, necessitating more powerful pumps and potentially affecting the system's energy consumption and mechanical durability. Therefore, while ethylene glycol offers stronger cooling capacity, particularly useful in high-performance or cold-climate EVs, water remains the more balanced and energy-efficient option for standard vehicle operation. These findings highlight the need to carefully consider both thermal and hydraulic performance when selecting coolants and designing microchannel configurations for advanced BTMS applications.

V. CONCLUSION

This study presents a comprehensive computational fluid dynamics (CFD) analysis of a microchannel-based Battery Thermal Management System (BTMS) for electric vehicle (EV) applications. By simulating a 10s4p lithium-ion battery module integrated with a serpentine microchannel cooling plate, the research evaluates the thermal and hydraulic performance of two common coolants—water and ethylene glycol—under steady-state, high-load conditions.

The results clearly indicate that microchannel cooling is an effective strategy for managing the high heat flux generated in densely packed battery systems.

The study concludes that microchannel-based liquid cooling is highly effective in managing heat in cylindrical lithium-ion battery packs for EVs, offering localized and efficient thermal control. Between the two coolants tested, ethylene glycol provided superior heat extraction (42°C drop, 0.5518 W/m² wall heat flux) but incurred a high pressure drop (~1557.2 Pa) due to its viscosity. Water delivered more balanced performance, with a 28°C temperature drop, lower wall heat flux (0.2267 W/m²), and reduced pressure loss (~741.4 Pa), making it more suitable for standard EV applications. Water also ensured smoother flow, better temperature uniformity, and improved safety by minimizing thermal hotspots and cell aging. The CFD simulations in ANSYS Fluent validated the design's effectiveness and supported informed coolant selection. Overall, water is recommended for general EV use, while ethylene glycol suits extreme conditions requiring enhanced thermal or antifreeze capabilities.

REFERENCES

[1] Chen, D., Jiang, J., Kim, G. H., Yang, C., & Pesaran, A. (2011). Comparison of different cooling methods for lithium-ion battery cells. Applied Thermal Engineering, 31(14–15), 3366–3376. https://doi.org/10.1016/j.applthermaleng.2011.06.019

[2] Fan, Y., Wang, X., Li, X., & Deng, Y. (2017). Design and performance analysis of microchannel cooling system for lithium-ion battery module. Journal of Power Sources, 352, 42–55. https://doi.org/10.1016/j.jpowsour.2017.03.128

[3] Hadad, Y., Baalbaki, A., & Saghir, M. Z. (2015). Heat transfer and pressure drop characteristics of serpentine microchannel configurations. International Journal of Thermal Sciences, 90, 290–297. https://doi.org/10.1016/j.ijthermalsci.2014.11.014

[4] Harpol, A., Mishra, R. S., & Singh, B. (2010). Simulation-based thermal analysis of lithium-ion battery packs in electric vehicles. International Journal of Heat and Technology, 28(2), 1–8.

[5] International Energy Agency. (2022). Global EV Outlook 2022: Securing supplies for an electric future. https://www.iea.org/reports/global-ev-outlook-2022

[6] Islam, M. R., Hasan, M. A., & Park, J. (2018). A review of thermal management in lithium-ion battery packs: Prospects of using phase change materials. Energy Conversion and Management, 177, 43–64. https://doi.org/10.1016/j.enconman.2018.09.089

[7] Kim, J., Lee, J., & Cho, B. (2023). CFD optimization of hybrid PCM-microchannel cooling systems for battery packs. Applied Thermal Engineering, 224, 120058. https://doi.org/10.1016/j.applthermaleng.2022.120058

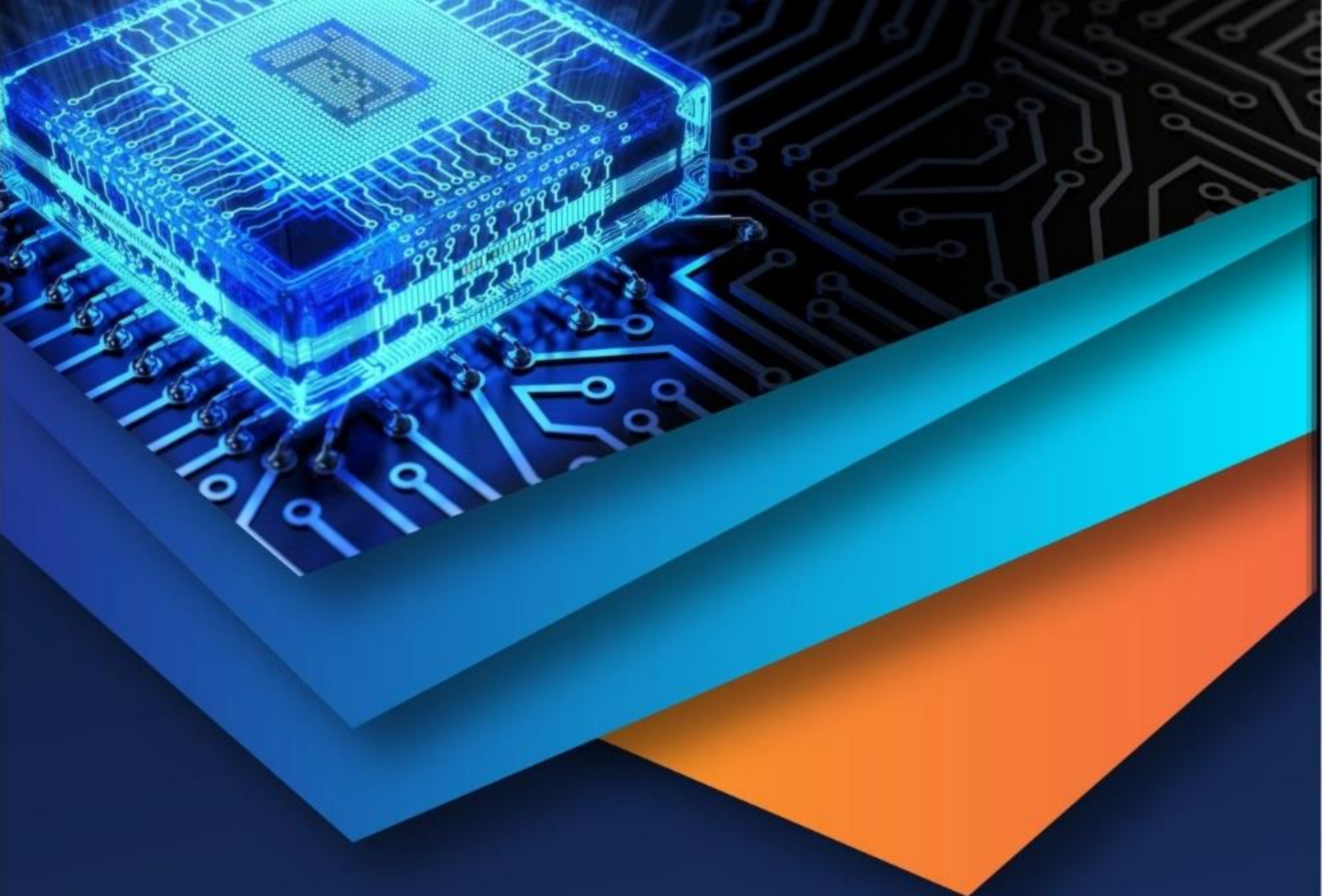
[8] Li, Y., Chen, H., Zhang, J., & Xu, J. (2021). Comparative analysis of water and ethylene glycol as coolants in microchannel battery cooling applications. Energy Reports, 7, 4116–4128. https://doi.org/10.1016/j.egyr.2021.06.030

[9] Mehta, N., Bansal, S., & Kumar, R. (2024). AI optimization for microchannel layout and flow distribution in battery cooling systems. Journal of Energy Storage, 74, 108880.

[10] Neubauer, J., & Wood, E. (2014). Thru-life impacts of driver aggression, climate, cabin thermal management, and battery thermal management on battery electric vehicle utility. Journal of Power Sources, 259, 262–275. https://doi.org/10.1016/j.jpowsour.2014.02.083

[11] Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. Nature Climate Change, 5, 329–332. https://doi.org/10.1038/nclimate2564

[12] Pesaran, A. A. (2001). Battery thermal management in EVs and HEVs: Issues and solutions. In Advanced Automotive Battery Conference (pp. 1–10). Las Vegas, NV.
[13] Prakash, S., Roy, S., & Ranganathan, S. (2014). Fabrication of high-precision microchannel structures using laser micromachining for thermal management. Microsystem Technologies, 20, 2119–2126. https://doi.org/10.1007/s00542-013-1923-5
[14] Sharma, T., Verma, A., & Yadav, N. (2023). Enhanced microchannel cooling using nanofluids and AI-based adaptive control strategies. Renewable and Sustainable Energy Reviews, 182, 113254. https://doi.org/10.1016/j.rser.2023.113254
[15] Song, Y., Wang, H., & Liu, Z. (2020). Experimental and numerical study on the thermal performance of a microchannel cooling plate for EV battery packs. Energy, 199, 117399. https://doi.org/10.1016/j.energy.2020.117399
[16] Wang, Q., Ping, P., Zhao, X., Chu, G., Sun, J., & Chen, C. (2012). Thermal runaway caused fire and explosion of lithium-ion battery. Journal of Power Sources, 208, 210–224. https://doi.org/10.1016/j.jpowsour.2012.02.038
[17] Wang, T., Tseng, K. J., Zhao, J., & Wei, Z. (2014). Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies. Applied Energy, 134, 229–238. https://doi.org/10.1016/j.apenergy.2014.08.015
[18] Xu, J., & Xu, B. (2019). Multi-objective optimization of battery thermal management system using microchannel cold plates. Applied Thermal Engineering, 153, 291–300. https://doi.org/10.1016/j.applthermaleng.2019.02.041
[19] Yadava, R., & Thombre, S. B. (2022). Design and simulation of serpentine and parallel microchannel cooling for Li-ion battery. Thermal Science and Engineering Progress, 29, 101228. https://doi.org/10.1016/j.tsep.2022.101228
[20] Zhang, X., Wang, C. Y., & Tang, X. (2015). Cycling degradation of an automotive LiFePO4 lithium-ion battery. Journal of Power Sources, 273, 775–782. https://doi.org/10.1016/j.jpowsour.2014.09.111
[21] Zhao, R., Liu, J., & Gu, J. (2016). The effects of cooling strategies on the cycle life of lithium-ion batteries. Energy Conversion and Management, 104, 1–9. https://doi.org/10.1016/j.enconman.2015.06.082
[22] Zou, H., Jin, Y., & Xu, X. (2018). Investigation of serpentine microchannel geometry on thermal performance of battery cooling plates. International Journal of Heat and Mass Transfer, 124, 236–247. https://doi.org/10.1016/j.ijheatmasstransfer.2018.03.089



10.22214/IJRASET

INDEX COPERNICUS

45.98

IMPACT FACTOR: 7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY