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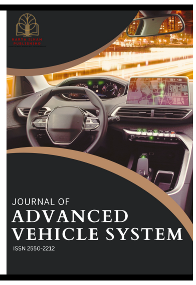

CFD Analysis of Electric Vehicle's Battery Thermal Management System

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ABSTRACT

The main sources of CO_2 emissions and environmental contamination are internal combustion engines and conventional gasoline. As a green energy solution for a cleaner future, electric vehicles are promoted. Lithium-ion batteries power EVs, but they have drawbacks such poor performance in extremely hot or cold temperatures, short electrode lifespans, and the potential for battery thermal runaway. Longevity of EVs depends on efficient battery thermal management systems (BTMs). In order to optimize the indirect liquid cooling system for EV batteries, this study highlights the critical roles that coolant selection, structural design, and channel configuration play. The impact of various coolants, different cold plate structures, and the number of channels were the three main parameters that were thoroughly addressed in this thorough CFD research employing a cold plate. The cold plate with serpentine-channel configuration, parallel and interdigited, is established in order to explore a straightforward and effective liquid cooling technique for the rectangular lithium-ion power batteries used in electric vehicles. The impact of coolant inlet temperature, channel arrangement, and cooling channel number on battery thermal management system cooling performance is then examined. The results of the numerical simulation show that the most effective cooling performance is achieved using a channel arrangement with three channels in a length-flowing direction. The maximum temperature can be lowered by 26 °C with this configuration as opposed to two or one channel. As the coolant's inlet temperature rises, so does the cooling system's maximum temperature. However, taking into account the cooling system's effectiveness and safety, there is a maximum restriction on the number of channels and the inlet temperature. The design of the cold plate for the thermal management system will benefit from the aforementioned outcome.

Keywords:
EV, battery thermal management system, CFD

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1. Introduction

Utilization of the alternate energy source become imperative in order to overcome the issues of global warming, climate change, and escalating population level. Regarding this issue, automotive industries can contribute by improving electric vehicles (EVs). There are several alternative energy storage systems, among which batteries are most feasible because of their average power delivery rates and efficient peak [7]. The most commonly used battery technology is the lithium-ion battery technology, due to its light weight, power, extended life cycle, and no memory effect. Moreover, lithium-ion batteries work finest at small temperature range i.e., 288.15 K to 308.15 K, and temperature for multi-cell module should not exceed 278.15 K [14].

In Electric vehicles, commonly used system for battery thermal management system (BTMS) is the liquid cooling system. Liquid cooling system are known to have higher cooling efficiency and compact structure. Various electric vehicles such as, Audi e-Tron, Chevrolet Bolt, Tesla Model 3 and Model S use the liquid cooling system. Generally, liquid cooling system is categorized into two methods such as direct and indirect method [3]. Batteries are placed in dielectric liquid in direct cooling method. Mineral oil, deionized water and silicon-based oil is used as dielectric liquid [3]. But due to some safety concerns, high power consumption and difficulty in selecting proper coolant, make it less feasible to be used in EVs [13].

Whereas the indirect method removes the heat from batteries by a coolant flowing through internal flow channels known as cooling plate. Indirect method used the water or water/glycol as coolant. It has been demonstrated that the cooling system performance relies on the cooling plate structure. The CFD study conducted by Jarret and Kim [9] on serpentine-channel cooling plate in order to optimize average temperature, pressure drop, temperature uniformity and pressure drop for BTMS. The effect on the cooling plate design was studied under different operating conditions and it was concluded that the temperature uniformity is the parameter that greatly effects [10].

For cooling the EV batteries, a novel oblique mini channel cooling plate was developed by Jarrett et al., [10]. The established that oblique cooling plate has higher transfer coefficient as compared to the conventional mini channel cooling plate.

The ideal temperature range for LFP batteries to operate safely and effectively is between 15 and 35 degrees Celsius. Each battery's temperature differential within a module or battery pack should be kept below 5°C. For LFP batteries, temperature control is pivotal to have the longest possible cycle life. Moreover, the internal degradation processes of battery are accelerated by the temperature above this range, leading to the increased internal resistance, decreased capacity and ultimately reducing its overall lifespan. Therefore, the thermal instability provokes chemical reactions that elevate temperature that could potentially lead to gas leaks, fires and explosions which may lead to the short circuit and destruction of the internal structure. Low temperature can also significantly influence the battery performance.

Internal resistance rises, battery electrolytes thicken, and the electrochemical reactions inside the battery slow down at lower temperatures. At lower temperatures, the electrolyte in LFP batteries may lose some of its conductivity. Slower charge and discharge rates may also be caused by this decline in electrolyte conductivity. To lessen these negative effects for the smooth working of battery, an appropriate BTMS is required.

In many electronic devices air is being used for heat transfer but for batteries air is not preferable coolant option because of the lower capacity to transfer heat which results low efficiency for heat transfer. Because of this low heat transfer efficiency battery surface temperature may rise resulting thermal runaway. Such an occurrence might potentially harm all batteries and can challenge the energy storage system performance. In the search of the solutions of the problems that raises when air is being used as coolant in battery the analysis was started in which air as a coolant is replaced by liquid coolants. In order to raise the performance and efficiency the battery pack with liquid coolant was introduced.

A Lithium Ion (li-ion) battery, rechargeable battery that store energy by using lithium ion. Due to its long lifecycle, high energy density and comparatively low self-discharge rate, it is widely used for renewable energy systems, portable electronics, and electrical vehicles.

It is widely used for electric vehicles, portable electronics, and renewable energy systems due to its high energy density, long cycle life, and relatively low self-discharge rate.

1.1 Need of Lithium Ion In Electric Vehicle:

- Because of the high energy density of Lithium-Ion batteries, electric vehicles (EV) can travel longer distances on a single charge
- For electric vehicles these batteries are appropriate because without experiencing significant degradation they can be charged and discharged thousands of times.
- Lithium-Ion batteries can quickly be charged, limiting its downtime and making electric vehicles user friendly.
- Lithium-Ion batteries discharge relatively slowly, suitable for electric vehicles that may not be utilized for long periods.

1.2 Problem Statement

In electric vehicles, thousands of batteries are coupled in parallel and series to make their energy storage system. Consequently, a significant amount of heat is produced as a result of charging and discharging, leading to the battery life degradation and impose serious safety hazards.

1.3 Objectives

i. To study the Battery thermal management system (BTMS) used for electric vehicles (EVs) batteries.
ii. To examine the flow configurations of various cooling plates used for electric vehicles batteries by employing numerical modelling and simulation.
iii. To analyse the different coolants used in EVs batteries by using numerical modelling and simulation

1.4 Purpose of Study

An effective thermal management system is required for EVs batteries because of the extensive heat generation during the charging and discharging of battery. In this study, different channel configuration of cooling plate will be analyzed to get uniform temperature distribution across the batteries. In addition to that, different coolants will be analysed to keep battery pack in a proper temperature range.

2. Methodology

In order to address the research question, this chapter presents the chosen research strategy and methodology. This thesis examined three distinct cooling channels. The goal of the three distinct cooling channels was to use Ansys Fluent to simulate and determine the best channel.

2.1 Channel Design

The efficiency of heat removal from the lithium-ion battery pack is largely dependent on the design of the cooling channels inside the cold plate. In order to assess the thermal and hydraulic performance of the four distinct channel configurations—single, double, triple, and parallel—this study designed and examined them. Serpentine channels increase the heat transfer surface area and improve thermal contact with the plate by forcing the coolant to flow over a meandering path, but they also cause higher pressure drops. The coolant covers a larger portion of the cold plate surface as the number of serpentine pathways rises (from one to three), which could improve temperature uniformity. Conversely, the parallel channel design permits coolant to pass through several straight channels at once, lowering pressure drop and flow resistance. However, because of potential flow misdistribution, this design may result in uneven cooling. CAD software was used to produce the designs for each setup as shown in figure 1.

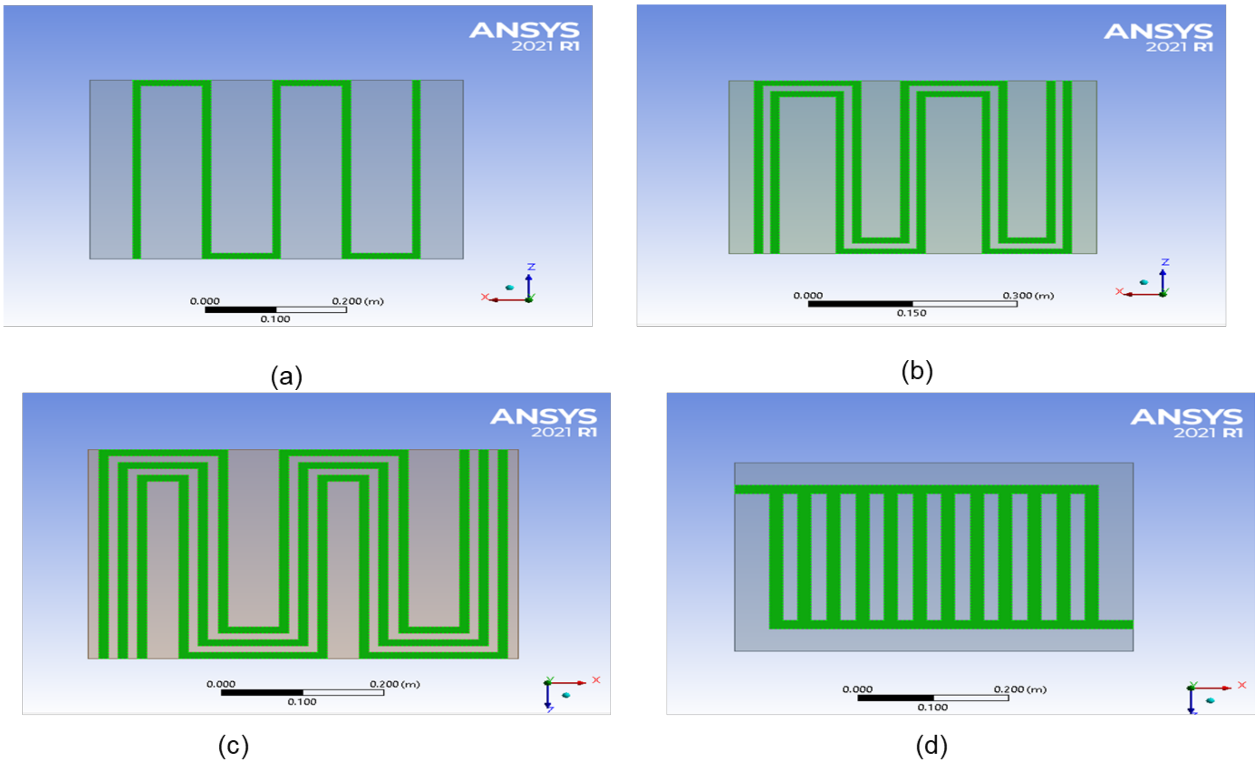

Fig. 1. CAD drawing of different flow channel configuration (a)1-serpentine, (b)2-serpentine, (c)3-serpentine, (d)parallel

2.2 Meshing Strategy

Since mesh generation directly impacts the accuracy, convergence, and computational efficiency of the results, it is a crucial step in the numerical simulation process. The meshing tools in ANSYS Workbench were used in this study to discretize the geometry of the cold plate with various channel configurations (single, double, triple, and parallel).

2.2.1 Mesh Type and Element Size

- **Mesh Type:** To manage the intricate internal channel routes, tetrahedral elements were employed in the fluid domain. When possible, hexahedral or prism elements were used, particularly for improved resolution in areas close to walls.
- **Zones of Refinement:** High-gradient areas (near inlets, outlets, and bends in serpentine pathways) were where mesh refinement was used.

Battery and cold plate interfaces (if modelled) close to the channel walls to record pressure variations and wall heat transfer

Element Size: The element size was determined based on a balance between solution accuracy and computational cost. For this simulation:

- Element size of cold plate is set to be 2mm.
- In regions where the fluid will flow in channel, the element size is set to be 0.5mm.

The meshing configurations for 1-serpentine, 2-serpentine, 3-serpentine and parallel channel are illustrated in figure 2.

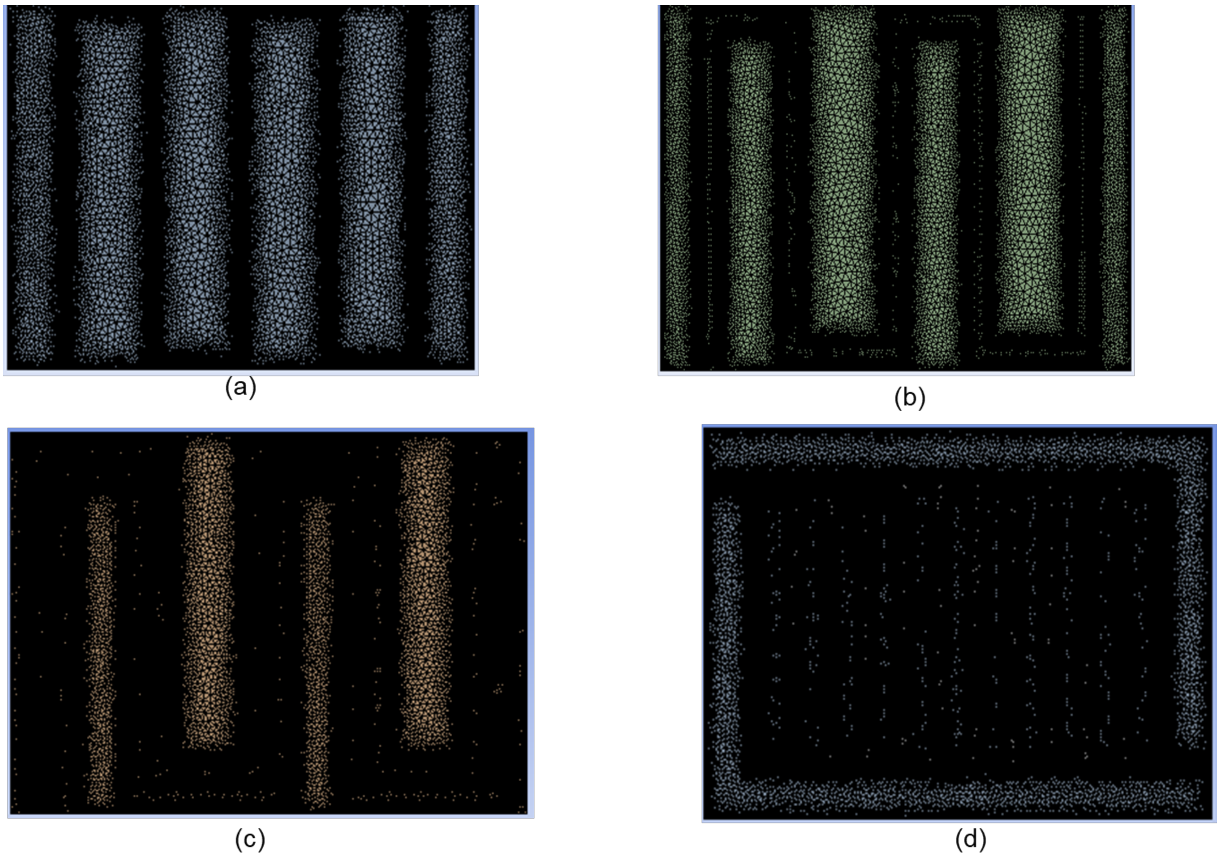

Fig. 2. Meshing of different flow channel configuration (a)1-serpentine, (b)2-serpentine, (c)3-serpentine, (d)parallel

2.2.2 Simulation Setup in Ansys

The procedures for digitally modelling and analysing the cold plate's thermal performance using ANSYS are described in the simulation environment setup. Assigning suitable material and fluid properties according to the selected coolants, specifying the flow channels, and producing a precise 3D geometry of the cold plate are all part of this step. Real operating conditions are replicated by applying boundary conditions including input temperature, flow rate, battery heat flux, and wall interactions. With refinement in crucial areas like channel bends and interfaces, a high-quality mesh is produced to guarantee accurate and dependable results. Lastly, the solver is set up to run steady-state thermal and flow simulations using energy equations, turbulence models (if any), and convergence criteria. This setup is crucial for capturing how each cooling channel design and coolant combination affects the temperature and pressure distribution within the system.

3. Results

3.1 Validation

Tao Deng et al. (2018) conducted a reference simulation study titled "Study on thermal management of rectangular Li-ion battery with serpentine-channel cold plate" that was published in the International Journal of Heat and Mass Transfer in order to verify the accuracy of the numerical model created in this investigation.

They employed a rectangular aluminium cold plate with inside serpentine passages to control a lithium-ion battery's temperature. They employed water as the coolant and supplied a consistent heat flux of 7000 W/m² to the plate's bottom surface. The inlet temperature was 30 °C, and the inlet flow rate was 10 g/s. The studies concentrated on the highest temperature at the heat source surface and employed a symmetry requirement to lower the computational cost.
The same temperature and flow boundary conditions were used to model a single, five-turn serpentine channel in order to reproduce this configuration. As shown in figure 3, the top surface, symmetry was applied and the geometry was suitably scaled. The reference paper reported a value of 43.253°C for a similar arrangement, however the maximum temperature projected by this study's simulation was 43.5°C.

The small variation of 0.57% attests to the consistency of the study's numerical configuration with results from the validated literature. Minor differences in discretization systems, meshing strategies, or solver tolerances could be the cause of the discrepancy. Nonetheless, the high degree of agreement in the maximum temperature suggests that the thermal model is trustworthy and appropriate for more simulations with various coolant kinds and channel configurations.

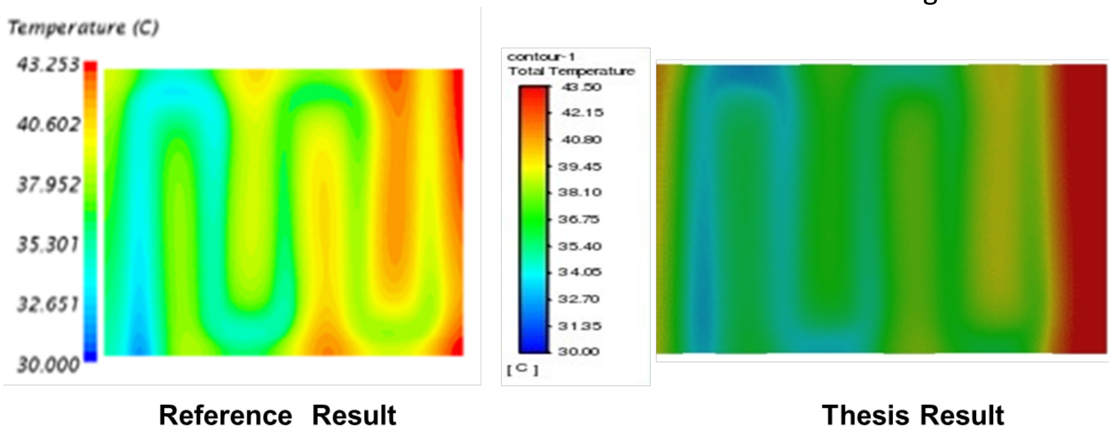

Fig. 3. Validation of simulation results

3.2 Different Flow Channel Configuration

For lithium-ion (Li-ion) batteries to remain safe, functional, and long-lasting, heat management is crucial. Effective cooling techniques aid in preserving the proper temperature and averting thermal runaway, a hazardous overheating condition. The temperature and pressure changes in five distinct cooling channel designs—one-, two-, three-, parallel, and interdigitated—are examined in detail in this chapter. Additionally, it contrasts the performance of three distinct coolants in each design: water, 25% ethylene glycol (EG), and 50% EG. The results are discussed in terms of how they impact battery cooling system efficiency and design.

3.3 Temperature Distribution Analysis

3.3.1 Temperature Distribution in Single Serpentine

Figure 1 looks at the 1-serpentine channel and the effects of different coolants. The coolants utilized include water, 25% ethylene glycol, and 50% ethylene glycol. Coolants like ethylene glycol are usually added to raise the freezing point of the coolant. The temperature distributions for water, 25% ethylene glycol, and 50% ethylene glycol are shown in Figures 4.

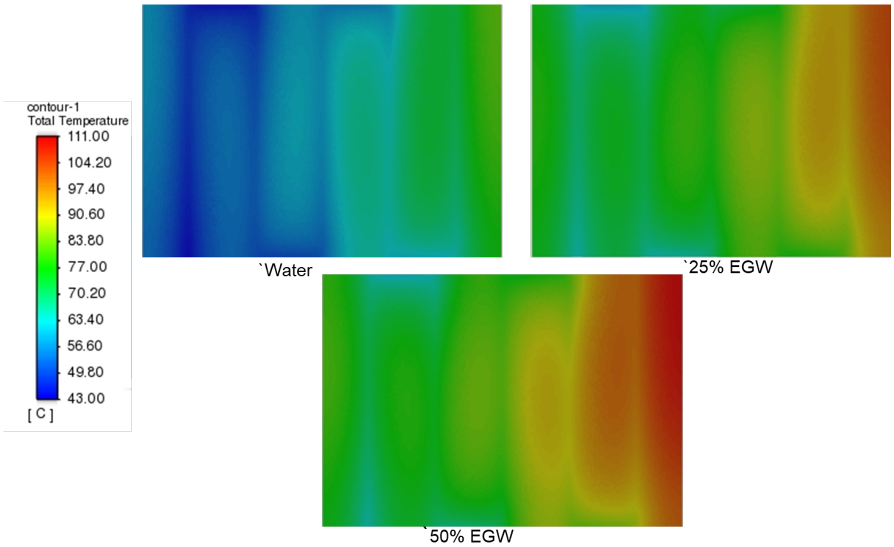

Fig. 4. Temperature contour of 1-serpentine at different coolants

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When water is used as a coolant, the lowest temperature at the inlet is 28.96°C (301.96 K) and the maximum temperature at the outlet is 82.79°C (355.79 K). Figure 23 makes it clear that the intake side generates a blue-green tint and is colder. Nevertheless, the temperature progressively increases from yellow to red as the fluid passes from the input to the output. This suggests that the high temperature close to the outflow is caused by weak viscosity and strong heat conductivity.

Using 25% ethylene glycol as a coolant, results in the lowest temperature at the intake being 35.72°C and the highest temperature at the output being 110.98°C. Since the viscosity of the fluid increases and its specific heat and thermal conductivity decreases when ethylene glycol is added to water, it is clear from Figure 24 that a larger red area indicates less efficient cooling. As a result, the temperature of this mixture rises above that of water. The 50% ethylene glycol mixture has a somewhat more consistent temperature contour but shows poor cooling effectiveness, with a maximum temperature of around 103.97°C. Since increasing the proportion of ethylene glycol frequently lowers cooling efficiency, pure water is the most effective coolant in this comparison.

3.4 Temperature Distribution in Two Serpentine

This section examines the 2-serpentine channel and the impact of various coolants. Water, 25% ethylene glycol, and 50% ethylene glycol are the coolants used. In order to raise the coolant's freezing point, coolants such as ethylene glycol are typically added. Figure 26 displays the temperature distribution for water, Figure 27 displays the temperature distribution for 25% ethylene glycol, and Figure 5.

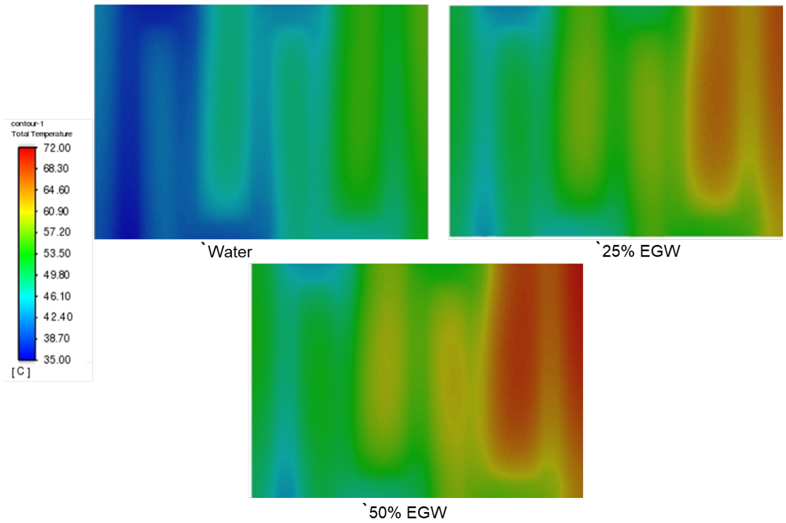

Fig. 5. Temperature contour of 2-serpentine at different coolants

The minimum temperature at the inlet when using water as a coolant is 35.10°C (308.1K).and the outlet's highest temperature is 56.91°C (329.91 K). Thus, there is a 21.81^{o}C (294.81 K) temperature differential. It is evident from Figure 26 that the majority of the blue and green area denotes a uniformly low temperature. This is due to the addition of an additional channel to the cold plate, which aids in maintaining consistent cooling and the water's ability to transmit heat effectively. The lowest temperature at the intake is 43.92°C (316.92K) when 25% ethylene glycol is used as a coolant, while the highest temperature at the outlet is 71.53°C (344.53K). Because ethylene glycol reduces heat transfer performance by increasing viscosity and decreasing thermal conductivity, Figure 27 shows a red area at the cold plate's output. The lowest temperature at the inlet is 43.05°C and the highest temperature at the output is 67.70°C when 50% ethylene glycol is utilized as the coolant. Consequently, there is a 24.65oC temperature differential. Figure 28 makes it evident that there are Red Zones, albeit they are not as strong as the 25% EGW.

3.5 Temperature Distribution in Three Serpentine

This section examines the 3-serpentine channel and the impact of various coolants. Water, 25% ethylene glycol, and 50% ethylene glycol are the coolants used. In order to raise the coolant's freezing point, coolants such as ethylene glycol are typically added. Figure 6 displays the temperature distribution for water, 25% ethylene glycol, and for 50% ethylene glycol.

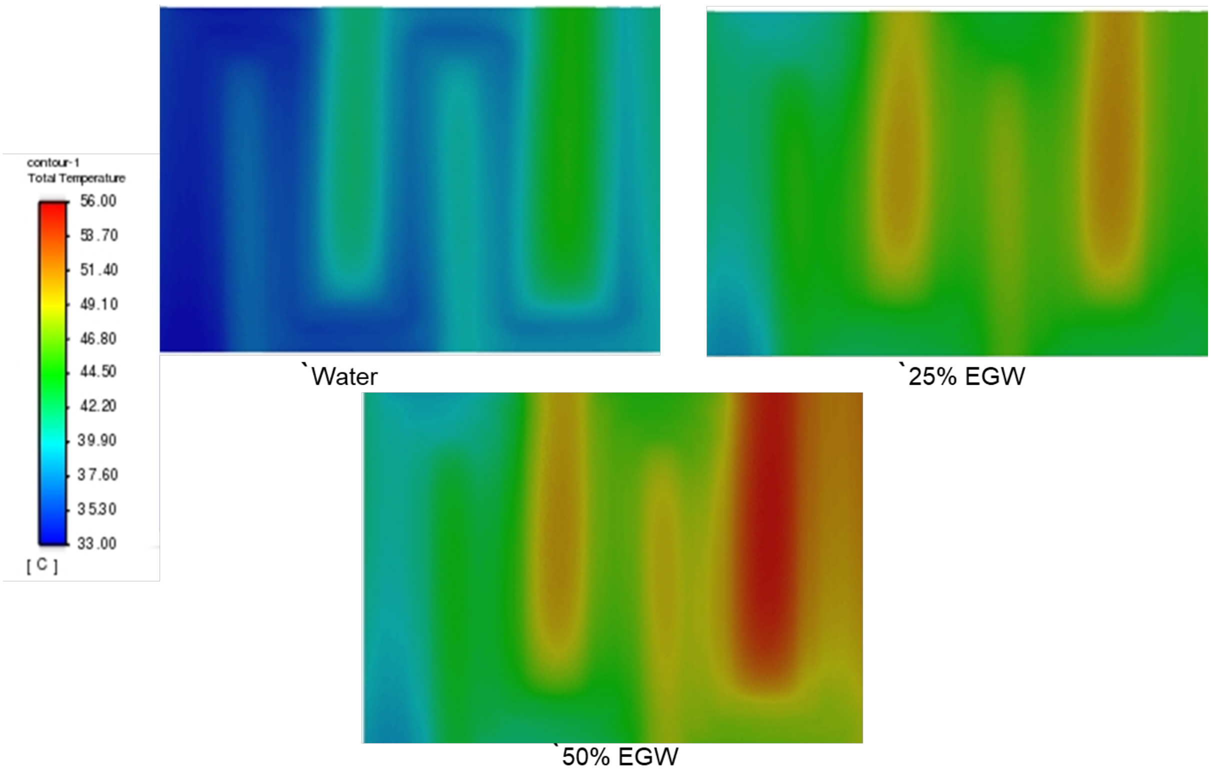

Fig. 6. Temperature contour of 3-serpentine at different coolants

Water is the most efficient coolant in the three-serpentine cooling arrangement, with the lowest maximum temperature of about 44.8°C and the lowest minimum temperature of about 32.7°C, according to the temperature distribution data. Water's high specific heat capacity and thermal conductivity enable it to absorb and transport heat more effectively throughout the 3-serpentine design's extended flow route, resulting in this higher performance. Water's temperature contour shows a primarily blue and green pattern, suggesting a consistent, well-controlled thermal profile with few hotspots.

In contrast, the mixture containing 25% ethylene glycol has the highest maximum temperature, which is roughly 56.6°C (329.6 K), and the lowest temperature, which is about 37.8°C (318.8 K). The glycol solution's higher viscosity and decreased thermal conductivity impede heat circulation and transfer, leading to more red zones and increased heat accumulation, especially in the direction of the exit. At a maximum temperature of roughly 55.8°C (331.8 K) and a minimum temperature of about 38.1°C (311.1% K), the 50% ethylene glycol mixture exhibits a slightly more uniform distribution because of smoother flow characteristics, outperforming the 25% solution by a little margin.

It still holds onto heat better than water, though. While both ethylene glycol combinations show decreased thermal performance, with the 25% mixture being the least effective, water offers the best overall cooling in the 3-serpentine arrangement.

3.6 Temperature Distribution in Parallel Channel

There was little pressure drop because the parallel channel arrangement provided the least amount of barrier to coolant flow. In contrast to the serpentine designs, the temperature distribution was less consistent, with certain regions experiencing greater temperatures as a result of the unequal flow distribution. Figure 7 depicts the temperature distribution for water, for 25% ethylene glycol, and for 50% ethylene glycol.

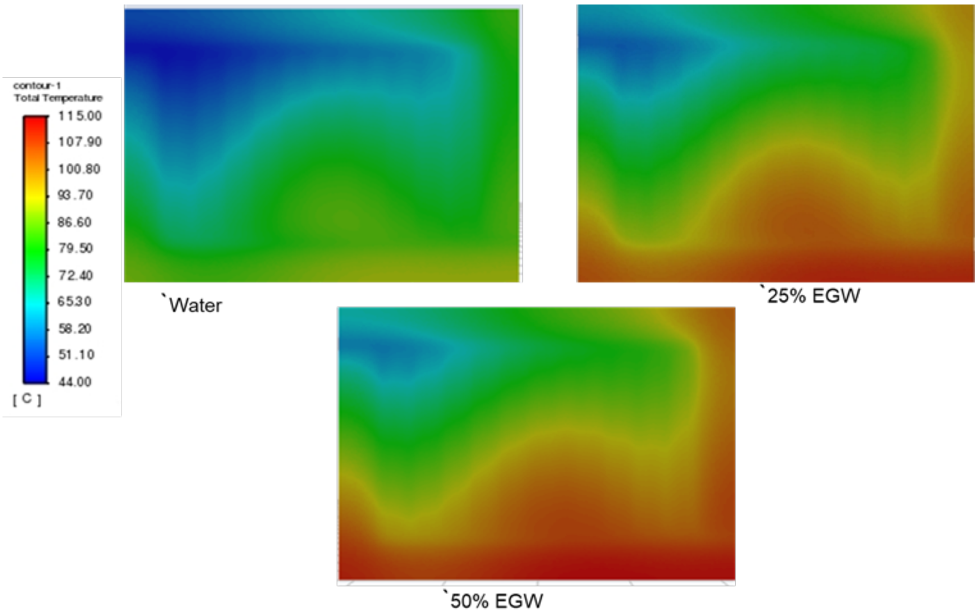

Fig. 7. Temperature contour of 3-serpentine at different coolants

The temperature distribution results indicate different cooling effectiveness for water, 25% ethylene glycol, and 50% ethylene glycol in the parallel channel arrangement utilized to cool a lithium-ion battery. With a minimum temperature of roughly 44.8°C and a maximum temperature of roughly 91.7°C, water performs the best among these. In contrast to the glycol-based coolants, the contour displays a more efficient and consistent heat dissipation, with the intake and mid-region displaying dominating blue and green zones that change to yellow and red at the outlet. Water is beneficial because of its high thermal conductivity and low viscosity, which enable it to absorb heat rapidly and move via parallel routes with efficiency.

On the other hand, the 25% ethylene glycol mixture exhibits the highest temperature recorded in this configuration, with a minimum temperature of about 54.5°C and a maximum temperature of about 111.8°C. Larger red zones in the contour, particularly close to the outflow, show a considerable buildup of heat. The glycol mixture's increased viscosity and weaker thermal conductivity are blamed for this subpar performance since they restrict its capacity to effectively transfer heat away, creating thermal hotspots. With a high temperature of 115.1°C and a minimum of roughly 58.5°C, the 50% ethylene glycol mixture outperforms the 25% solution by a small margin; nonetheless, its overall temperature profile still exhibits noticeable red and yellow areas. Although flow stability is marginally enhanced by the greater glycol percentage, the drawback of decreased thermal conductivity remains.

4. Conclusion

The goal of this study was to understand how different coolant flow designs and fluids impact the cooling of a lithium-ion battery pack using a cold plate system. Four channel configurations—1-serpentine, 2-serpentine, 3-serpentine, and parallel—were tested with three types of coolant: pure water, 25% ethylene glycol mixture, and 50% ethylene glycol mixture. Through simulations in ANSYS, the temperature distribution and pressure drop across the cold plate were recorded to evaluate both cooling efficiency and the energy required to pump the fluid.

One of the most important takeaways is that water consistently delivered the best cooling performance. It kept the surface temperature of the cold plate lower than any glycol mixture across all channel designs. This is mainly because water has a high heat capacity and low viscosity, which allows it to absorb and transport heat more effectively. However, its downside is the lack of antifreeze protection, which means it can't be used in cold climates unless precautions are taken to prevent freezing.

When it comes to channel design, the 3-serpentine layout clearly stood out. It provided the most uniform cooling, with the smallest temperature difference between the inlet and outlet areas. This uniformity is essential in battery cooling, as large temperature gradients can lead to uneven battery aging and even thermal runaway in extreme cases. Even though the 3-serpentine had a slightly higher pressure drop than the parallel channel, the trade-off was justified by the substantial improvement in thermal performance.

In contrast, the parallel channel design had the lowest pressure drop, meaning it required the least amount of pumping power. While this might seem like an advantage at first, it also had the worst thermal performance in terms of temperature control. This makes it more suitable for low-heat generation systems, but not for high-performance battery packs where heat needs to be managed precisely.

To sum it all up, the best choice for cooling lithium-ion batteries in high-performance or safety-critical systems would be a 3-serpentine cold plate with water as the coolant, assuming environmental temperatures remain above freezing. If operation in cold environments is expected, switching to a 25% ethylene glycol-water mixture would be a good compromise, still offering decent thermal performance while preventing freezing. These insights can help engineers and designers create more reliable and efficient battery cooling systems in real-world applications.

References

[1] Buchmann, Isidor. 2017. *What Is C Rate?* Batteries in a Portable World.

[2] Chemicool Dictionary. n.d. "Cathode, Anode." *Chemicool Dictionary.* https://www.chemicool.com/definition/cathode-anode.html.

[3] Chen, J., S. Kang, Z. J. Huang, K. Wei, and B. Zhang. 2019. "Effects of Different Phase Change Material Thermal Management Strategies on the Cooling Performance of Power Lithium-Ion Batteries." *Journal of Power Sources.* https://doi.org/10.1016/j.jpowsour.2019.227228.

[4] Davoodabadi, A., C. Jin, D. L. Wood III, T. J. Singler, and J. Li. 2020. "On Electrolyte Wetting through Lithium-Ion Battery Separators." *Extreme Mechanics Letters* 100960. https://doi.org/10.1016/j.eml.2020.100960.

[5] Deng, T., G. Zhang, and Y. Ran. 2018. "Study on Thermal Management of Rectangular Li-Ion Battery with Serpentine-Channel Cold Plate." *International Journal of Heat and Mass Transfer*, 143–152. https://doi.org/10.1016/j.ijheatmasstransfer.2018.04.065.

[6] Dinçer, I., S. H. Hamut, and J. N. Yildiz. 2017. *Thermal Management of Electric Vehicle Battery Systems.* https://doi.org/10.1002/9781118900239.

[7] Ecolithiumbattery. n.d. "What Are $LiFePO_4$ Prismatic Cells?" *Ecolithiumbattery.* https://www.ecolithiumbattery.com/what-are-lifepo4-prismatic-cells/.

[8] Jarrett, A., and Y. I. Kim. 2011. "Design Optimization of Electric Vehicle Battery Cooling Plates for Thermal Performance." *Journal of Power Sources*, 10359–10368. https://doi.org/10.1016/j.jpowsour.2011.06.090.

[9] ———. 2014. "Influence of Operating Conditions on the Optimum Design of Electric Vehicle Battery Cooling Plates." *Journal of Power Sources*, 644–655. https://doi.org/10.1016/j.jpowsour.2013.06.114.

[10] Liang, X., Y. Yang, X. Jin, and J. Cheng. 2016. "Polyethylene Oxide-Coated Electrospun Polyimide Fibrous Separator for High-Performance Lithium-Ion Battery." *Journal of Materials Science & Technology* 200–206. https://doi.org/10.1016/j.jmst.2015.11.006.

[11] Liu, X., L. Zhang, and L. Guo. 2018. "An Improved Perturb and Observe MPPT Algorithm for Wind Turbines under Rapidly Changing Wind Speeds." *Renewable Energy* 115: 362–374. https://doi.org/10.1016/j.renene.2017.08.06.

[12] Pesaran, A. A., S. Santhanagopalan, and H. G. Kim. 2013. "Addressing the Impact of Temperature Extremes on Large Format Batteries." [Publication details unavailable.]

[13] Qin, Q., X. Li, Z. Wang, J. Wang, G. Yan, W. Peng, and H. Guo. 2023. "Experimental and Simulation Study of Direct Current Resistance Decomposition in Large Size Cylindrical Lithium-Ion Battery." *Electrochimica Acta* 142947. https://doi.org/10.1016/j.electacta.2023.142947.

[14] Rajagopalan Kannan, D. R., P. K. Terala, P. L. Moss, and M. H. Weatherspoon. 2018. "Analysis of the Separator Thickness and Porosity on the Performance of Lithium-Ion Batteries." *International Journal of Electrochemistry.* https://doi.org/10.1155/2018/1925708.

[15] Sauer, W. 2009. "A Critical Review of Battery Thermal Management." [Publication details unavailable.]

[16] Tseng, Y. M., H. S. Huang, L. S. Chen, and J. T. Tsai. 2018. "Characteristic Research on Lithium Iron Phosphate Battery of Power Type." *MATEC Web of Conferences.* https://doi.org/10.1051/matecconf/201818500004.