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Simulation on the thermal management of electrical vehicle battery pack with different cooling methods

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Abstract. Electrical vehicles (EVs) are becoming more popular every day. Lithium ion (Li-ion) batteries in the cylindrical form are utilized as the power source of both electrical vehicles and hybrid electric vehicles due to their small size and high-power density. There is typically very little space between the batteries. Heat dissipation must be properly evaluated to ensure that the battery operates as intended. The study goal is examine how well a battery pack performs overall while using alternating cooling strategies. Three models were created in solidworks 2016 for the purpose of determine the best cooling approach. Three battery thermal management (BTMs) options were also chosen, analyzed, and simulated in Ansys Fluent 19.2 to ensure accurate and thermal modelling. According to the findings, geometry 2 ethynyl glycol exhibits a more efficient temperature distribution and maximum temperature than the other cooling methods. Furthermore, channel cooling based on BTMs, the consistent temperature distribution is carried out, and the maximum temperature is regulated to 306.66 K, with a minimum temperature of 293. 20 K being attained.

Keywords : Battery Pack, Electric Vehicles, Cooling system, BTMS, Li-Ion Cell, ANSYS Fluent.

1. Introduction

The temperature profile of lithium-ion batteries is a crucial factor in the efficiency and performance of electric vehicles (EVs). In fact, the temperature of the battery pack can have a significant impact on the range and lifespan of an electric vehicle. Lithium-ion batteries are preferred over lead-acid batteries for electric vehicles due to their higher energy density, power density, and longer lifespan. However, they are also more sensitive to temperature changes, and extreme temperatures can cause damage to the battery cells, reducing their performance and lifespan. To maintain equal temperatures in the battery pack and ensure optimal performance, electric vehicles use sophisticated battery management systems (BMS)

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that monitor and control the temperature of the battery pack. These BMS systems use sensors to monitor the temperature of each battery cell and adjust the charging and discharging rates to maintain the desired temperature range. Overall, maintaining a stable temperature profile in the battery pack is essential for ensuring the efficiency and longevity of electric vehicles. As the technology continues to evolve, we can expect to see further improvements in battery management systems and cooling/heating systems that will help to optimize the performance of lithium-ion batteries in EVs.

The role of Lithium-Ion Batteries (LIBs) in electric vehicles is highly dependent on the battery temperature, as higher temperatures can impact the performance and lifespan of the battery cells. EVs typically have multiple battery modules that are arranged in a series or parallel configuration to provide the desired voltage and capacity. If the module size is increased beyond what is required, it can lead to an increase in the amount of heat generated inside the battery pack. This can cause the battery cells to heat up beyond their safe operating temperature, which can lead to a thermal runaway event [1]. LIBs can generate heat during their normal operation due to various factors such as the rate of charging or discharging, internal resistance, and the age and condition of the battery. If the heat generated exceeds the maximum safe limit, it can lead to thermal runaway, a condition where the battery temperature rises rapidly, causing a chain reaction that can result in the battery exploding or catching fire [2]. In terms of efficiency, EVs convert around 55% of the energy from the battery to power the wheels, while Internal combustion engine (ICE) vehicles typically have an efficiency of around 25%. This is because ICE vehicles lose a significant amount of energy to heat and friction, and they must also use some of their energy to power ancillary systems like air conditioning and power steering. The process of converting electrical energy from the grid station to power at the wheels involves several energy conversions, which can result in heat generation and energy losses. One of the main sources of heat generation in batteries is ohmic losses, which occur due to the internal resistance of the battery cells. The resistance of the battery cells leads to the conversion of some of the electrical energy into heat, which can cause the battery temperature to rise. Another source of heat generation is the activation and concentration gradients within the battery cells, which can lead to chemical reactions and the generation of heat. Battery manufacturers try to minimize these effects by reducing the internal impedance of the battery cells, which can help to reduce the heat generation rate. During fast charging, the batteries can dissipate more heat due to the higher current and power levels involved. This can lead to a significant rise in the battery temperature, which can damage the battery cells and reduce their lifespan [3- 4].

A battery management system (BMS) is essential for the optimal performance of EV batteries. The main objective of the BMS is to ensure the safe and efficient operation of the battery pack by monitoring and controlling various parameters such as state of charge (SoC), state of health (SoH), and temperature. One critical aspect of BMS design is the need to maintain a uniform temperature distribution along the battery pack. Temperature gradients within the battery pack can lead to thermal runaway, reduced battery life, and increased safety risks. Therefore, BMS designers aim to implement heating and cooling systems to maintain a uniform temperature distribution and prevent temperature gradients from developing [5]. A three-dimensional battery pack can offer several advantages over a traditional two-dimensional design, including higher energy density, improved heat dissipation, and more efficient use of space. However, the performance of a three-dimensional battery pack can be affected by the surrounding air temperature, which can impact the thermal behavior of the battery cells. Therefore, it is important to investigate the performance of a three-dimensional battery pack under different air temperature profiles. This can involve using computational models to simulate the thermal behavior of the battery pack under different conditions, as well as conducting experimental tests to validate the models and measure the actual performance of the battery pack [6]. This study was investigating the thermal behavior of a battery pack with 36 LIB cells. The study focused on the effects of different parameters, such as mass flow rate, heat flux, and spacing size, on the thermal behavior of the battery pack. The results of the study indicate that the air spacing between the batteries can have a significant impact on the thermal behavior of the battery pack. By shortening the air spacing between the batteries from 23.9 K to 2.1 K, the author was able to improve the thermal performance of the battery pack by 91.2%. This suggests that optimizing the spacing between battery cells can be an effective way to improve the thermal behavior of battery packs and reduce the risk of thermal runaway [7].

The study conducted by M. Y. Ramandi, focused on improving the thermal performance of a phase change material (PCM) shell by developing a double-layered PCM shell around the existing shell. The study investigated the heat transfer characteristics of the PCM shell using the finite volume method and compared the outcomes with the exergy losses. The results of the study indicated that the double PCM shell system with insulated walls performed the best among the three prototypes, with no significant temperature difference observed between the insulated and non-insulated double shell systems. This suggests that the double-layered PCM shell can effectively improve the thermal performance of the PCM shell, and insulation may not be necessary in some cases. In addition, the study also conducted a numerical simulation on a Li-ion power battery pack to investigate the convective heat transfer of an air-cooling system. This type of analysis can help to optimize the design of battery cooling systems and improve the thermal management of battery packs [8]. Investigated the effects of different factors on the thermal behavior of adjacent battery cells. The study specifically focused on the spacing between adjacent cells, the type and velocity of ventilation, and the temperature of the entrance air. Based on the results of the experiment, the study concluded that there is an initial increase in temperature difference between adjacent cells when the spacing between them is too small or too large. However, with the increase of wind speed, there is a relative drop in temperature difference. Therefore, it is important to choose an optimal spacing between adjacent cells to avoid excessive temperature differences [9].

Over the past decade, battery thermal management systems have adopted many cooling techniques to help dissipate the heat generated by the batteries. These techniques include air cooling, liquid cooling, phase change materials, and active thermal management systems. Air-cooling is one of the commonly used cooling techniques for battery thermal management systems. It involves circulating air over the battery pack to remove heat generated during operation. Air-cooling is a simple and low-cost option that can be effective for many applications. However, it may not be sufficient for high-power applications or for battery packs with a high cell density, as the airflow may not be able to reach all areas of the pack. In addition, air-cooling may not be effective in hot climates where the ambient air temperature is high [10 – 15]. Liquid cooling can also be used in battery thermal management systems to help regulate the temperature of the battery pack. Batteries generate heat during charging and discharging, and high temperatures can reduce battery performance and lifespan or even cause safety issues. In a liquid-cooled battery thermal management system, the coolant is circulated through channels or tubes that are in direct contact with the battery cells or modules. The coolant absorbs heat from the batteries and carries it away, helping to regulate the temperature of the battery pack. This method of thermal management can provide more precise control of battery temperature than air cooling or passive cooling methods, and can help to extend the life of the battery pack [16 – 17]. Phase change materials (PCMs) can also be used in battery thermal management systems to provide passive cooling or as a backup cooling system. In such systems, the PCM is placed in contact with the battery cells or modules and absorbs the heat generated by the batteries as they charge and discharge. When the temperature of the battery pack rises above a certain level, the PCM melts and absorbs the heat, thus preventing the battery from overheating. As the temperature drops, the PCM solidifies and releases the stored heat. This process helps to regulate the temperature of the battery pack and can extend the life of the battery. Using PCMs in battery thermal management systems can provide several advantages. For example, it can reduce the size and complexity of the cooling system and improve the reliability and safety of the battery. It can also help to reduce the energy consumption of the cooling system and improve the overall efficiency of the battery [18 - 19]. Experiment on battery thermal management using liquid cooling with a flat heat pipe. The use of different cooling methods and coolant flow rates is an important factor to consider when designing a battery thermal management system, as it can have a significant impact on the battery temperature and performance. comparing the results of the liquid cooling with flat heat pipe to other cooling methods, the researchers can identify which cooling method is most effective for different discharge rates and coolant flow rates. This can help to optimize the design of battery thermal management systems and improve their performance and reliability [20].

Interesting study on the use of nanofluids for cooling electronic devices. The use of nanofluids, which are fluids containing nanoparticles, has gained attention in recent years as a potential way to enhance heat transfer and improve the cooling performance of electronic devices. The study of the hybrid nanofluid of aluminium oxide and silver particles for heat transfer of a solid block, as well as the numerical study of the hybrid carbon nanofluid application in a rectangular microchannel, provides valuable insights into the potential use of nanofluids for cooling electronic devices. The finding that single-wall carbon nanotubes can be used in advanced cooling applications is particularly interesting, as it suggests that nanofluids containing carbon nanotubes may have potential applications in electronic cooling systems. Carbon nanotubes are known for their high thermal conductivity, which makes them a promising material for enhancing heat transfer in cooling systems [21 – 23].

The study focused on identifying the primary acceleration of electric and hybrid electric vehicles at a constant power region. This is an important factor to consider when designing the propulsion system of such vehicles, as it can help optimize the power rating of the system and ensure efficient performance. The use of minimal power rating for identifying primary acceleration is an interesting approach, as it suggests that the power rating of the propulsion system can be optimized to achieve the desired acceleration performance while minimizing energy consumption. This can help improve the overall efficiency and range of electric and hybrid electric vehicles [24]. study that focuses on the aero heating phenomena under different geometrics of a spike, and the use of computational fluid dynamics (CFD) to analyze the heat generation phenomena. Aero heating is a critical factor to consider in the design of high-speed vehicles, such as supersonic and hypersonic aircraft and missiles, as it can cause significant damage to the vehicle's structure and components. The study's conclusion that the use of a spike at the frontal region of the nose can reduce aero heating is an important finding. A spike can be used to reduce the intensity of shock waves generated by the vehicle's nose, thereby reducing the amount of heat generated due to aero heating. This finding has practical implications for the design of high-speed vehicles, as it suggests that incorporating a spike can help reduce the vehicle's overall heat load [25].

By varying the coolants and their volume fractions, this study can provide valuable insights into the optimal design and performance of automobile radiators. ANSYS software is a powerful tool that can simulate the fluid flow and heat transfer in the radiator, allowing researchers to analyze the effect of different coolant properties and their concentrations on the radiator's performance. By varying the coolants and their volume fractions, this study can provide valuable insights into the optimal design and performance of automobile radiators. ANSYS software is a powerful tool that can simulate the fluid flow and heat transfer in the radiator, allowing researchers to analyze the effect of different coolant properties and their concentrations on the radiator's performance [26]. Study that proposes a cooling system for an electric vehicle battery pack and examines its efficiency under different flow velocities of the coolant at different discharge rates. Battery thermal management is a critical factor to consider in the design of electric vehicles, as it can significantly impact the battery's performance, safety, and lifespan. The finding that the optimum range of coolant flow velocity is lower than 45°C is an important observation, as it suggests that excessive cooling may not be necessary and may even have negative effects on the battery's performance and lifespan. By identifying the optimal range of coolant flow velocity, designers can develop more efficient and effective battery thermal management systems that can help improve the overall performance and safety of electric vehicles [27]. Study that investigates the use of hybrid nanofluids in a spiral plate heat exchanger and compares their performance with that of water and nanofluids. Heat exchangers are widely used in various industries for transferring heat between two fluids, and the use of nanofluids can enhance their thermal performance. The results of this study suggest that the combination of hybrid nanofluids can provide better thermal performance than water and nanofluids. Hybrid nanofluids are created by combining two different types of nanoparticles in a base fluid, and they have been shown to exhibit enhanced thermal conductivity and heat transfer performance compared to single-component nanofluids [28 – 29].

Analyze the thermal performance of trapezoidal cut twisted tape using computational fluid dynamics (CFD) and Fe3O4 nanofluid. Twisted tape inserts are widely used in heat exchangers to enhance the heat transfer rate between fluids by creating turbulence and increasing the effective surface area. The results of this study suggest that the use of trapezoidal cut twisted tape with a twist ratio of 4.0 can provide better thermal performance and higher heat transfer rate compared to plain tubes. The study focused on Reynolds number ranges from 2000 to 12000, which are typical ranges for many industrial applications [30].

The paper aims to investigate and identify the most effective cooling method for ensuring the optimal operation of electric vehicles. To accomplish this, the authors have designed and analyzed three different cooling geometries using ANSYS software. Specifically, two geometries are used for channel cooling and one geometry for air, direct liquid cooling. The study focuses on the use of 18650 cylindrical lithium-ion batteries for developing the battery pack, which is a commonly used battery type in many electric vehicles. The analysis of different cooling methods is crucial in maintaining the battery temperature within an optimal range, which is important for safety of the battery. The use of ANSYS software enables the authors to simulate and analyze the thermal performance of the battery pack under different cooling conditions. By comparing the results of the different cooling geometries, the authors hope to identify the most effective cooling method for ensuring the efficient operation of the electric vehicle.

2. Model and Methodology

2.1 Channel cooling (side cold plate)

Channel cooling, also known as side cold plate cooling, is a type of cooling technique used to dissipate heat from electronic components, such as processors, memory chips, or power electronics. In this technique, a cold plate is placed on one side of the component, and a coolant flows through channels within the plate, absorbing the heat generated by the component and carrying it away. The coolant can be a liquid, such as water or a specialized coolant fluid, or a gas, such as air or nitrogen. The channels within the cold plate can be straight or serpentine, depending on the specific application and thermal requirements. Figure

1 shows the geometrical models of channel cooling. Ethylene glycol with water (50/50% by volume) and water alone are used as coolant through the channels.

Figure 2 shows the graph between ethylene glycol solution (% by volume) and temperature. The combination of ethylene glycol and water solutions is commonly used in heat transfer and in heating applications. Ethylene glycol is frequently used for heating and cooling purposes. If excess ethylene glycol is used there is a chance of leakage so as an alternative solution, propylene glycol is generally used.

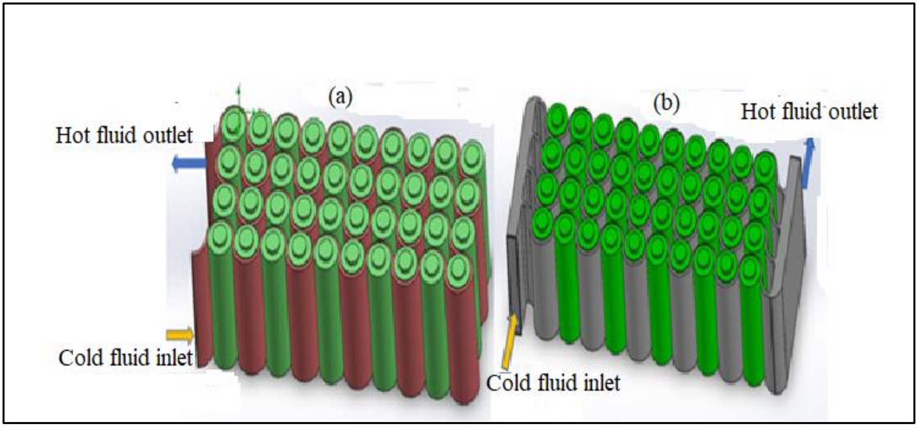


Fig. 1. Channel cooling model (a) Geometry 1 (b) Geometry 2

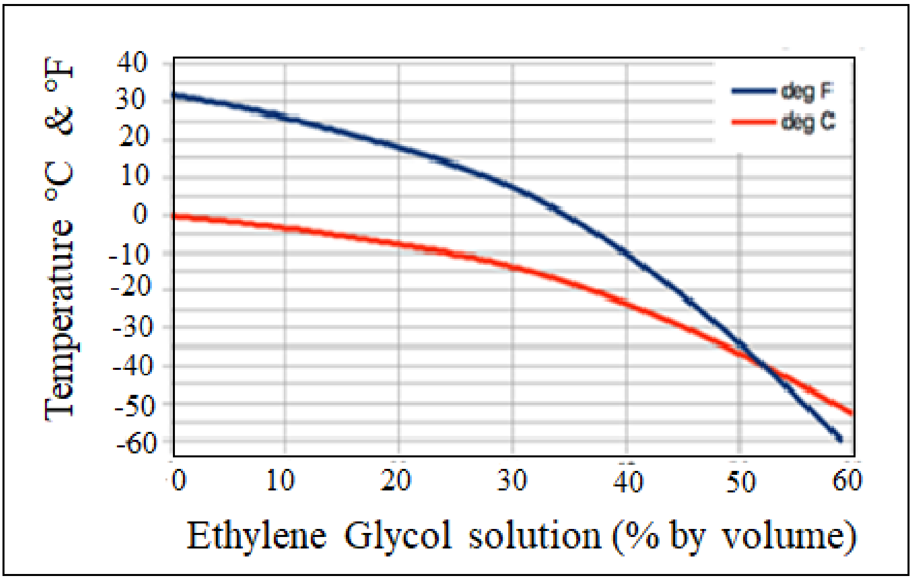


Fig. 2. Ethylene glycol solution (% by Volume) vs Temperature

2.2 Air cooling and Liquid cooling

Different geometric models of Li-Ion battery are developed and subjected to different cooling techniques. The models are designed in SolidWorks and analysed in ANSYS Fluent software. Cooling methodology were analysed using conjugated heat transfer CFD simulation. Cylindrical LIB cells have a diameter of 18mm and height of 70mm. The battery module has 40 cells and these are positioned with 3mm cell spacing throughout the battery pack. For air and direct liquid cooling's the physical model is same. A 3 mm distance is maintained between two adjacent cells like earlier models. To avoid bigger constraints top and bottom portions of the geometry are neglected so heat transfer between the cells is investigated for simulation work. For fluid cooling air, water and ethylene glycol are considered as coolants

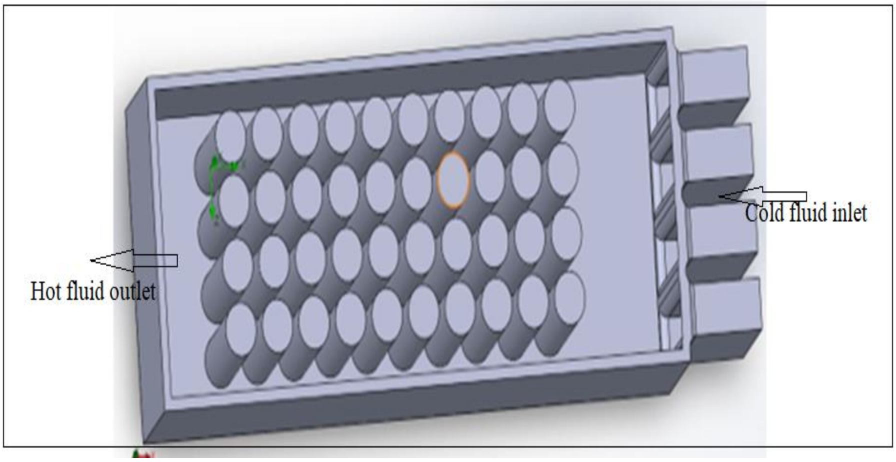


Fig. 3. Geometry 3 for Air and Direct Liquid cooling model

3 Methodology

3.1 Mesh sensitivity analysis

In the simulation process meshing is an essential area of engineering problem solving where complex geometrics are splitted into simple elements. That will be treated as local resemblance of huge domain**.** The mesh improves the accuracy, convergence and speed of the simulation. So, suitable meshing is generated by using generate mesh in ANSYS Fluent. The battery module was designed for different cooling methods as shown in Fig 4.

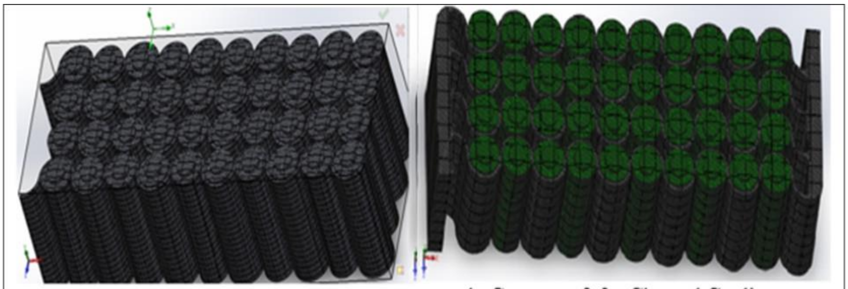
3.2 Initial and Boundary condition

3.2.1 Inlet condition

Inlet boundary condition is based on the water pump that is selected for the project work. The water pump selected is Seaflo 1100 GPH 12v Boat Marine Plumbing Electric Bilge Pumps. Converting 1100 gallon per hour to m^3/s gives Inlet Condition = 0.001388889 m^3/s. with the fluid temperature of 293K.

3.2.2 Outlet condition

The fluid is considered to be working under atmospheric pressure. So, Outlet condition is 101325 Pa. Batteries are assumed to be maintained at a temperature of 330 K (57 °C, worst case scenario), which is a real wall temperature of the surface. For the simulation a pressure-based k-epsilon turbulent, incompressible, transient solver is considered.



a. Geometry 1 for Channel Cooling

b. Geometry 2 for Channel Cooling

c. Geometry 3 for Air & Direct Liquid Cooling

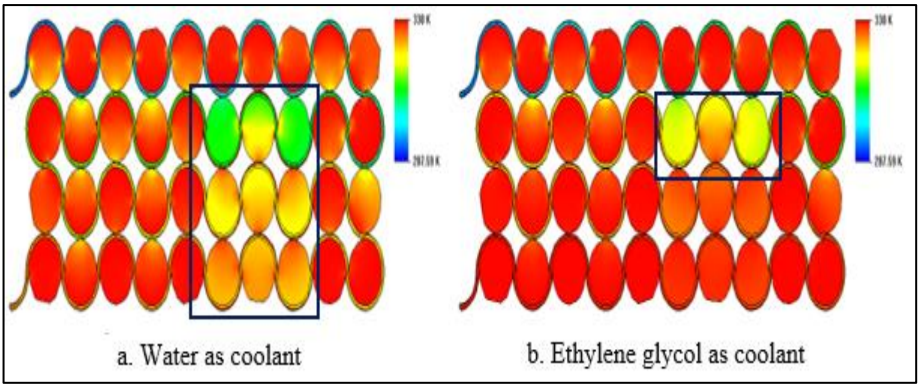
Fig. 4. Meshed geometrics for cooling methods (a) Geometry 1 channel cooling (b) Geometry 2 channel cooling (c) Geometry 3 Air & Direct liquid cooling

4 Results and Discussion

4.1 Channel cooling

4.1.1 Geometry 1

The surface of the cells is in contact with the pipe. Water is used as coolant and passed at inlet to the outlet as shown in Figure 5 (a) whereas ethylene glycol is used as coolant and passed at inlet to the outlet as shown in Figure 5(b). Figure 5(a) shows that when water is used as coolant 6,7,8 cells of 2nd , 3rd, 4th rows the temperature was uneven but in Figure 5(b) when ethylene glycol is used as coolant 6,7,8 cells of 2nd row the temperature distribution is better compared to Figure 5(a) because as the flow is unidirectional (single inlet and single outlet), the temperature absorption is very less at the end of the circuit and the cells near at the inlet are cooler than those at the outlet and at the end of the cooling channel is the hottest cell. So, for the same geometry, ethylene glycol has more temperature absorption than water. As a result, the temperature distributed from 293.20 K to 326.37 K. Hence, temperature distribution is uneven in the battery pack.

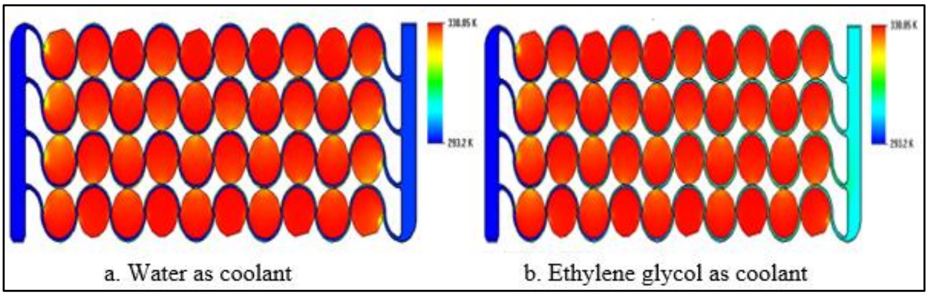


a. Water as coolant b. Ethylene glycol as coolant

Fig. 5. Horizontal temperature distribution with Channel cooling (a) Water coolant (b) Ethylene glycol coolant

4.1.2 Geometry 2

A new model (geometry 2) was designed. The surface of the cells is in contact with the pipe. Water is used as coolant and passed at inlet to the outlet as shown in Figure 6 (a) whereas ethylene glycol is used as coolant and passed at inlet to the outlet as shown in Figure 6 (b). Based on CFD results, the cells near the inlet are cooler than those at the outlet and at the end is much better than geometry 1. In this analysis, Figure 6b shows the maximum temperatures reached is 306.66 K and minimum temperature reached is 293.20 K. So, the temperature is distributed from 293.20 K to 298.49 K. By comparing the fluids involved, ethylene glycol has better heat absorption than water. So, average bulk temperature of ethylene glycol is 305.28 K whereas for water it is 295.67 K. Moreover, the limitation in the first geometry has been overcome in this geometry, which makes temperature distribution is even in the battery pack.



a. Water as coolant b. Ethylene glycol as coolant

Fig. 6. Horizontal temperature distribution with Channel cooling (a) Water coolant (b) Ethylene glycol coolnat

4.2 Air cooling

The same geometry was designed for air and direct liquid cooling. But when air cooling is considered, air is taken as coolant and when direct liquid cooling is considered ethylene glycol is chosen.

4.2.1 Geometry 3

As shown in the Figure 7, air is used as coolant for air cooling method. The cells in the battery pack are immersed in a fluid because air is considered as fluid. In the Figure 7, shows the fluid flow via the cells in the battery pack. Since, the flow is in single direction the temperature at starting column is low and it is quite opposite at the other end. This is because with every column the temperature is accumulated. Hence, the maximum temperature is 330 K and minimum temperature is 324 K, whereas temperature of the air is 293 K. Average temperature distribution is 308.77 K.

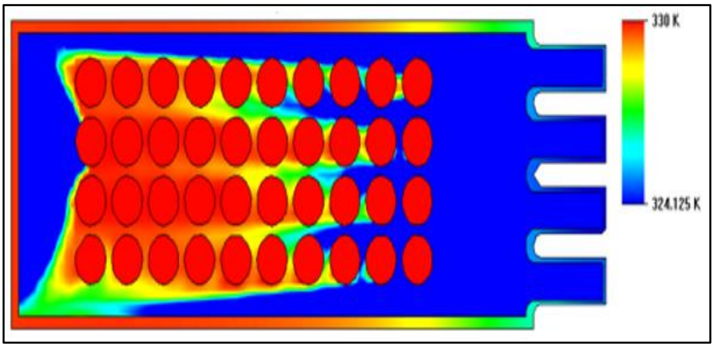


Fig. 7. Horizontal temperature distribution of air cooling

4.3 Direct liquid cooling

4.3.1 Geometry 3

Because of same geometry, parameters which are considered for the analysis are same except the fluid so in Figure 8, ethylene glycol is taken as immersion fluid and simulation has done. From the results it was observed that in air-cooling system, heat is stagnated to a certain area; thereby heat dissipation is almost negligible. At this point the temperature of that area is equal to that of cell temperature. So, from Figure 8, the max temperatures reached to 330 K. But when the density and viscosity of the fluid are considered, it was observed that from immersed liquid cooling as the max temperature dropped to 302.58 K for the same geometry. Not only the max temperature dropped, the temperature distribution on an average is 296.51 K which is 12 °C lower than immersed air cooling. So, immersed liquid cooling provides more efficient temperature distribution than air cooling.

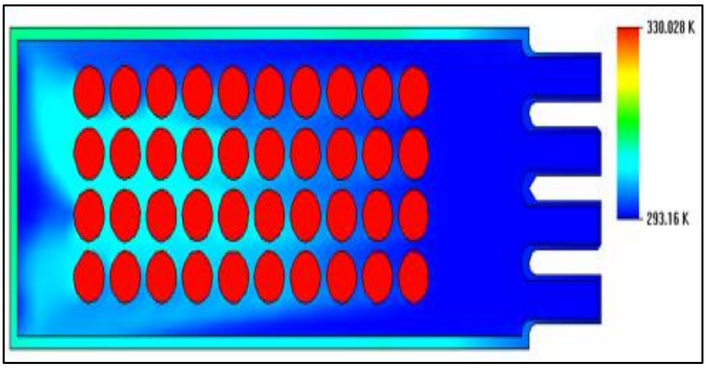


Fig. 8. Horizontal temperature distribution of direct liquid cooling

Table 1. Comparison of various cooling techniques for different geometrics

Type of cooling	Outcomes	Cooling medium		
		Air	Ethylene glycol	Water
Geometry 1 (Channel cooling)	Average temperature at outlet	--	328.7 K	323.8 K
	Temperature distribution	--	35.79 K	30.89 K
Geometry 2 (Channel cooling)	Average temperature at outlet	--	305.31 K	295.69 K
	Temperature distribution	--	12.31 K	2.69 K
Geometry 3 (Direct liquid cooling)	Average temperature at outlet	--	295.58 K	--
	Max. temperature	--	302.58 K	--
Geometry 3 (air cooling)	Average temperature at outlet	302.64 K	--	--
	Max. temperature	329.72 K	--	--

5 Conclusions

In the current analysis, a 3D model was developed to study the thermal behaviour of LIB module. A user-defined function is implemented for studying heat transfer in the battery cell**.**

- Geometry 2 has better heat distribution than geometry 1 and immersed cooling. But the temperature difference in geometry 1 is higher this is because there is only single flow path, whereas geometry 2 has multiple flow paths meeting at same destination.
- In air cooling, the drawback is the temperature absorption is very high at starting and low at the ending. Not only that, in the middle part of the pack, temperature distribution is very low.
- The same goes for immerse cooling, but due to the viscosity of fluid, temperature distribution is much better than air cooling.

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