WJAETS

World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(Review Article)

Thermal management lithium-ion battery for electric vehicles with using cold plate

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World Journal of Advanced Engineering Technology and Sciences, 2024, 12(01), 087–094

Publication history: Received on 04 April 2024; revised on 13 May 2024; accepted on 16 May 2024

Article DOI: https://doi.org/10.30574/wjaets.2024.12.1.0191

Abstract

Lithium-ion batteries are widely employed as the primary energy storage solution for electric vehicles (EVs). Effective thermal management of these batteries within EVs is important to ensure their safety, optimal performance, and longevity. Lithium-ion batteries are sensitive to fluctuations in temperature, and if not managed correctly, these temperature variations can lead to issues like overheating, reduced efficiency, and even safety risks. This study aims to investigate the effectiveness of a cooling method for a prismatic NMC battery used in electric vehicles. It emphasizes the significance of maintaining the battery's temperature within a specific range, typically between 15 °C and 35 °C, to prevent capacity loss and extend the battery's life. The design of the minichannel cold plate allows for precise thermal control with the 7 °C temperature difference. It efficiently absorbs heat generated during battery operation and releases it, preventing the battery from reaching undesirable temperature levels. Furthermore, the study underscores the importance of optimizing the contact area between the coolant and the battery stack for superior performance of the liquid cooling system. At higher discharge rates of the battery, a greater flow rate is required to achieve efficient cooling, with certain limitations due to the cooling system's efficiency. Overall, the study highlights the advantages of employing a liquid cooling system for proficient temperature regulation and effective heat dissipation in battery stacks for EVs.

Keywords: Thermal management; NMC battery; Mini channel cold plate; CFD simulation; Temperature and Pressure distribution.

1. Introduction

Electric vehicles (EVs) are emerging as an efficient means to lessen the environmental effect of conventional internal combustion engines in the quest for green transportation. An essential component of electric vehicles' lifetime and performance is effectively handling their lithium-ion battery power source. There is a growing demand for innovative heat management solutions, greater driving ranges, and faster charging periods to ensure safe and optimal battery performance.

Rechargeable Lithium-Ion Batteries (LIBs) are used in large quantities in the form of stacks in electric vehicles (EVs) for powering an induction motor that propels the vehicles while it is in use [5]. Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate (LFP), Lithium Nickel Cobalt Aluminum Oxide (LCA), Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO)), and Lithium Titanate (LTO) are the several types of LIBs. NMC batteries outlast other LIBs in lifespan, are more affordable, and offer a greater energy density [1].

Lithium-ion batteries' inherent temperature sensitivity is a major drawback, particularly for high-demand applications like electric cars. High temperatures have the potential to hasten deterioration, impair functionality, and endanger safety, underscoring the vital need for efficient thermal control. Novel ways are required to solve the drawbacks of

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traditional liquid cooling systems, which frequently failed offer equal variation in temperature as well as rapid dissipation of heat.

The purpose of this study is to investigate and propose a novel approach to lithium-ion battery thermal management for electric vehicles: the incorporation of a layered design that involves the cold plate and battery cells. This method seeks to improve heat transfer efficiency, lessen thermal gradients, and eventually increase battery longevity while maximizing performance by integrating various components into a cohesive whole.

his study explores the basic principles of heat control in lithium-ion batteries, analyzing with liquid cooling methods. Liquid cooling is the most commonly employed cooling method [2], typically implemented in two primary approaches: direct cooling and indirect cooling. The widely adopted method is indirect cooling, where a nonconductive liquid circulates through channels that come into contact with the battery modules, absorbing heat from them. Subsequently, this heat is released into the external environment through a heat exchanger or radiator fan. This method operates on the principle of conduction. The concept of conduction drives this method's operation.

The direct cooling method, in which the fluid makes direct contact with the battery, is a further form of liquid cooling. This process requires a coolant having a low coefficient of expansion that is nonconductive. Direct cooling is still in the research and development stage because of these strict criteria [3]. It further extends the battery life of the EV and greatly improves power delivery and battery efficiency. Its construction guarantees that it uses less energy and that the batteries don't become too hot [4]. Commercial vehicles like the Chevrolet Volt, Tesla Model S, and Model X, BMW i3 new, Jaguar Pace, Audi e-Tron, and Toyota iQ feature liquid cooling thermal management systems.

Computational fluid dynamics, a computer-based analysis method, is used to model fluid movement and transfer of heat in the cold plate. To determine temperature gradients, pressure distributions, and velocity vectors, CFD analyzes the entire heat transfer in separated components. Designing the battery with several modifications is made very simple by CFD; otherwise, it would be incredibly costly and impractical to do it physically. CFD models are frequently utilized because they can give ideal solutions and can project performance under risky conditions. They provide the outline along with information that estimates the performance of the lithium-ion battery pack.

2. Battery Heat Generation

The pace at which a battery charges and discharges is the main factor contributing to temperature elevation. There are two primary ways that heat is generated in Li-ion batteries: the Joule effect, which is based on the resistance within during electron transport, and the electrochemical processes or entropy change. greater current flow from greater charging or discharging rates causes more power to be dissipated, which raises the temperature. To comprehend its thermal properties, Bernardi and associates were simulating the piotery [5]. A mixture of reversible and irreversible heat components may be utilized to numerically represent the heat produced inside a battery [6].

$$Qtot = Qirr + Qrev$$

$$= I^2 + I(\partial U/\partial T)$$

The cell's current, open-circuit voltage, terminal voltage, and temperature are represented by the letters I, U, V, and T in these equations, respectively. The first term represents the rate at which heat is produced irreversibly as a result of the cell potential deviating from its equilibrium potential.

The quantity of heat produced is affected by several variables [7]

- State of charge: strongly correlated with both the electrochemical reactions and the diffusion of lithium ions;
- Temperature: increases electrochemical reactions and reduces internal resistance at high temperatures;
- Electrochemistry: active materials have a major impact on the quantity of heat produced;
- State of health: internal resistance rises with age.

3. Battery Management system

Any battery that consumes energy, whether it is for an electric vehicle or an electrical appliance, must have a battery management system (BMS). Its primary duty is to keep an eye on and preserve the safety, performance, and health of batteries. Features:

- Track the temperature of each individual cell in the battery pack.
- Takes measurements of voltage, current, and temperature;
- employs sensors to check the battery's temperature and in response to the temperature reading, turns on the cooling system.
- Maintains the batteries' ideal operating temperature.

4. Battery Thermal Management Systems

The most crucial features of a BTMS are its compact size, affordability, simplicity of installation, stiffness, dependability, and ease of maintenance [8]. Practical applications mostly employ Liquid-Based BTMS Liquid-cooled systems because of their high efficiency and compact design. Since liquid has a high heat capacity and heat transfer coefficient, it is an appropriate option for EVs' BTM [9]. Compared to an air-cooling system, two to three times less energy is required to keep the batteries' average temperature constant [10].

There are two types of liquid cooling techniques: indirect and direct cooling. DIRECT cooling, as submerged cooling involves the battery or pack in circulating dielectric coolants like oil, while indirect cooling routes the fluid transfer with tubes or jackets, passing it surrounding the cooling plate or battery compartment where the packs are located [11]. Pumps and radiator help move the coolant and dissipate heat. This liquid collect heat from battery and subsequently dissipates it into the surrounding environment via a radiator fan. As it operates indirectly, this cooling method relies on the principle of conduction.

5. CFD Modelling

The battery pack used in the EV is used as a cold plate upon which rectangular stack cells are stacked. This article's goal was to construct and investigate a cold plate used in larger Li-ion battery vehicles. The principles and zigzag patterns seen on cold plates are shown in Figures 2 and 3. In general, a cold plate is a heat exchanger where heat from the battery pack is absorbed by coolant that is continuously flowing.

Table 1 Specifications of the NMC prismatic battery

Specification	Value
Rated Capacity (Ah)	37
Voltage (V)	3.7
Specific energy (Wh/kg)	150-220
Height (mm)	33
Width (mm)	17
Length (mm)	100
Life Cycle	1500-2000
Rated Energy (kWh)	1.62

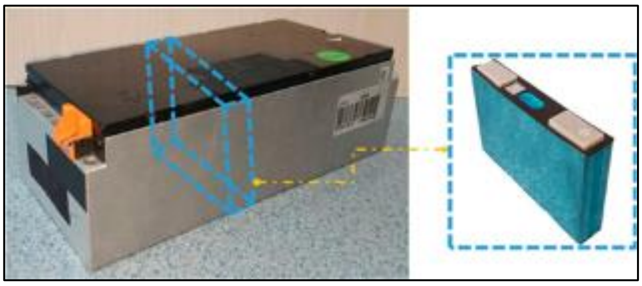


Figure 1 The real picture of the battery module [12].

The cold plates are often constructed with a channel flow design to contain the maximum amount of heat surface that the coolant may absorb. It was possible to produce two cold plates, as shown in Figure 2. The external size cold plate is 100 mm × 33 mm × 4 mm. A larger pressure drop is possible because of the zigzag design. Consequently, a 2 mm radius was applied for the modeling process over the whole length of the plate, as shown in Figure 2.

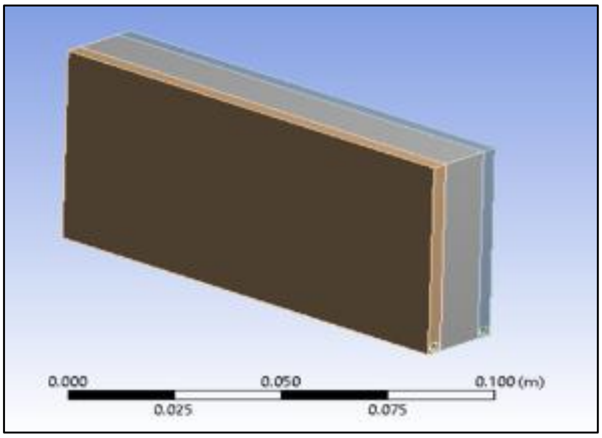


Figure 2 NMC battery model.

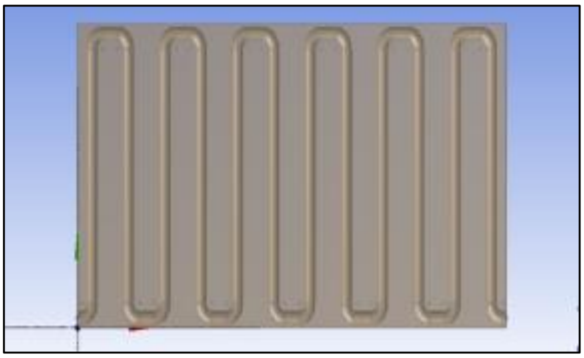


Figure 3 NMC battery cell with Zig zag channel cold plate.

For numerical simulation, the resources needed for each calculation domain must be obtained. In this inquiry, low-density aluminium with a high degree of thermal conductivity is chosen for the cold plate, and water with high specific heat and low viscosity is chosen as the coolant.

Determining the channels is necessary to ascertain the fluid's flow pattern. The kind of flow is defined by the Reynolds number, which is:

$$Re = \rho v D / \eta$$

Where ρ is the amount of water's density, v is the speed of the water, and D is the diameter. For the first analytical test run, the mass flow was adjusted to 0.5 m/s. Laminar flow, with a Reynolds number of <2000, corresponded to 995. In the analytical model, the laminar model needs to be chosen.

$$f = F\, 64 / Re$$

The cold plate's internal channel experiences a pressure decrease that is

$$\Delta p = v\, 2\, f\, l\rho / 2D$$

Where l is the path of the flow length, D is the diameter, f is the friction factor, and v is the speed of the fluid. F is the shape factor channels, and the formula for the friction factor is [13].

Table 2 Cold plate parameter

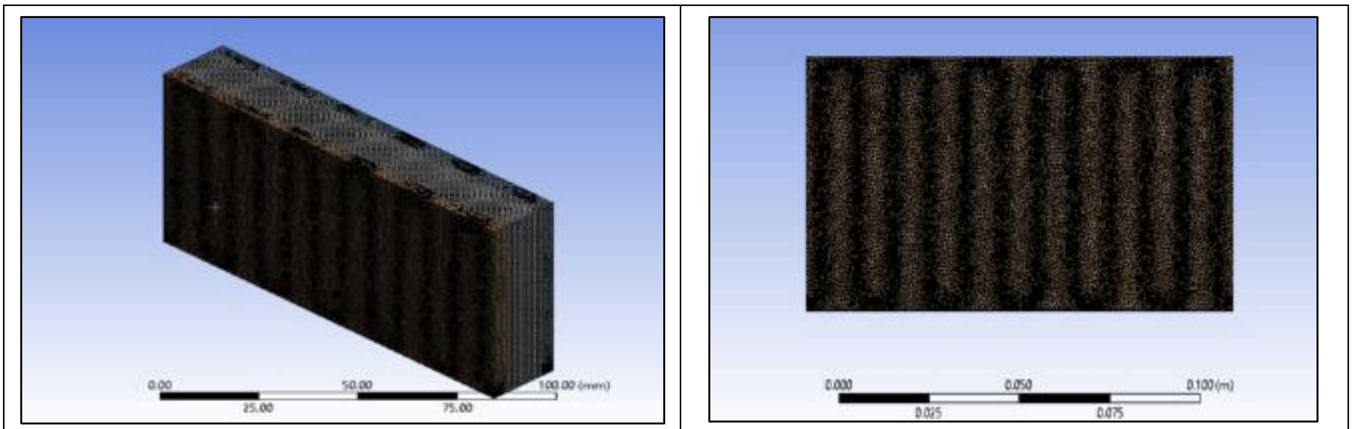
Specification	Value
Material	Aluminium
Density (Kg/m3)	2719
Thermal conductivity (w/m-k)	202.4
Specific heat (cp) (j/kg-k)	871
Length (mm)	100
Width (mm)	4
Height (msm)	33
Pipe diameter (mm)	2

Table 3 Liquid property

Specification	Value
Liquid	Water
Density	998.2 kg/m^3
Viscosity (μ)	.001003 kg/m-s
Thermal conductivity (k)	0.606 W/m.K
Specific heat capacity (c p)	4.18 kJ/(Kg.K)

6. Mesh generation

Lithium-ion (Li-ion) battery technology relies heavily on thermal control, especially in applications where durability, safety, and performance are crucial. Mesh creation is a basic stage in building models to simulate and study thermal behavior in the field of computational fluid dynamics (CFD). Because the characteristics, such as surface, volume mesh cells, cell nodes, and model element form, affect the model's numerical behavior and accuracy of findings, meshing the model is crucial. The default mesh, a fundamental component of CFD simulations, is used to start research into thermal management solutions for NMC batteries with cold plates to represent exact geometry and improve convergence as seen in Figures 4. (A) and (B).



(A) (B)

Figure 4 (A) & (B) Mesh generated NMC battery model.

7. Result

Computational fluid dynamics (CFD) simulations are used to analyze the temperature management techniques used in the lithium-ion battery system. Using the default meshes configurations entails providing temperature distributions, fluid velocities, and other pertinent characteristics that were collected from the simulations. To do this, it is necessary to explain the underlying causes causing the thermal behaviour that has been observed and to discuss the efficiency of various thermal management techniques in controlling the battery system's temperature and heat dissipation.

This study examined the cold plate's cooling capabilities. In the first investigation, the channel's diameter was fixed at 2 mm. Other boundary conditions were imposed, and water was placed as a liquid in the cold plate. We track variables including the cold plate's maximum temperature (Tmax), the pressure drops between the intake and exit (Δp), the heat transfer between the plate and the coolant (solid-liquid) interface (h), the average temperature (Tavg), and the temperature standard deviation (Tσ). The dependability of the results was compared with the results acquired after 1900 iterations. For the battery to regulate the temperature, the cold plate's temperature homogeneity was important.

As seen in Figure 5, a method was created to investigate how the distribution of temperature affected the channels in the cooling plate. With the 2C rate of discharge, the NMC battery's temperature is 47 °C [14]. Use a rate of mass flow of 0.5 m/s for the water coolant at the inlet and a liquid with a water temperature of 20 °C to get the desired outcome. In addition, the battery module's temperature fluctuation curves for the maximum temperature and temperature differential.

The coolant flows from the right to the left in the temperature distribution shown below in Figure 5. It is evident from the temperature gradient that the outflow area experiences the highest temperature, while the input portion has a lower temperature. This feature indicates that while coolant moves through the channel, the coolant continually absorbs heat dissipation. The highest temperature within the cells was 47 °C, whereas the estimated temperature across the cell surfaces was about 27 °C, with a 7 °C. An efficient way to remove heat from the battery and keep its temperature within a safe working range is to use liquid cooling techniques. As long as the coolant leaves the battery at 27 °C after exiting it at 20 °C, as in your particular case, the cooling system is successfully removing heat from the battery. It is suggested that heat is being transported from the battery to the coolant by the temperature differential (Δt) of 7 °C and the average temperature (T_{avg}) of 27 °C. This is important in order to prevent overheating and maintain optimal battery performance.

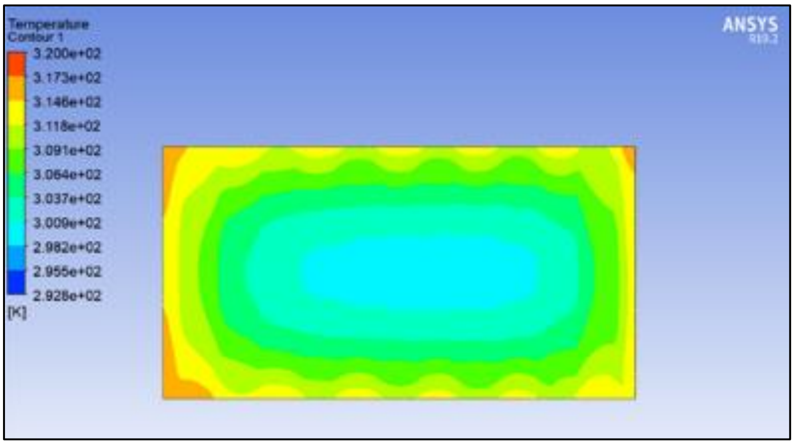


Figure 5 Temperature distribution on the cooling plate surface.

As seen in Figure 6, the overall temperature distribution of the channel is within an ideal range. The ideal range of temperature is 15 °C to 35 °C. The design and performance of the cooling system, the coolant's flow rate and thermal conductivity, the surrounding air temperature, and the battery's rate of heat generation should all be taken into consideration when assessing the cooling system's efficacy. To make sure that the cooling system sufficiently satisfies these needs, it's also critical to take into account the particular requirements of the Li-ion battery, such as its temperature tolerance limitations. Enhancing the thermal management for Lithium-ion batteries may improve their performance, efficiency, and longevity while guaranteeing safe operation in various operating circumstances. This can be achieved by optimizing the cooling system design and specifications.

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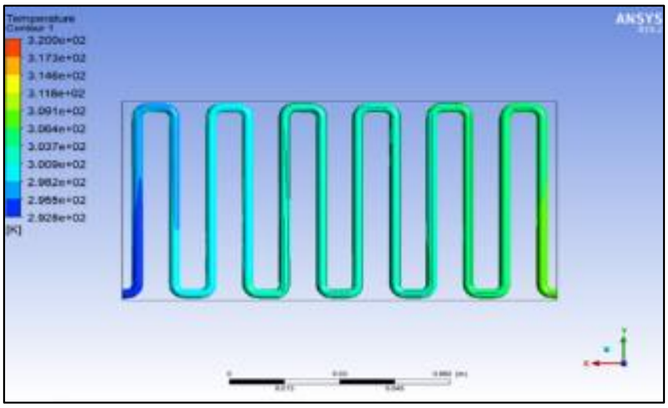

Figure 6 Temperature distribution on minichannel.

The study investigates the pressure distribution on the battery cold plate to optimize the liquid cooling system in Li-ion battery thermal management. The pressure changes throughout the cold plate's channels provide insight into potential concerns and fluid flow behavior. The study found high pressure at the inlet place, but as the coolant enters the intake zone, the interface zone expands, increasing resistance. As a result, the coolant flow pressure drops, causing a pressure drop (Δp). Different pressure gradients along the channels are observed, with greater pressures near the intake and lower pressures near the outflow. The fluid's characteristics, channel shape, and flow rate all affect these pressure changes. Pressure dips between the intake and exit provide information on the resistance the coolant faces. Successful liquid cooling systems require a thorough understanding of pressure distribution on the cold plate to maintain ideal temperatures and improve Li-ion battery system functionality and security.

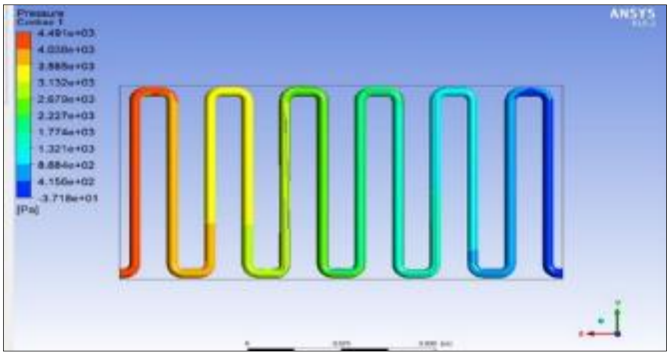

Figure 7 Pressure distribution mini-channel of cold plate.

8. Conclusion

It's true that the zigzag mini-channel design effectively dissipates heat from battery cells, keeping them operating within the ideal temperature range to improve longevity and performance. The zigzag mini channel design increases the region where the coolant and battery cells make surface contact, which is usually water, to improve heat dissipation. Better heat transmission is made possible by this design, which helps to control the NMC battery heat. The zigzag mini channel design keeps the NMC battery temperature within the ideal range of 15 °C – 35 °C, preventing overheating, which can reduce both lifespan and performance. Simulations using CFD are utilized to evaluate the cold plate cooling system's performance. The efficiency of heat transmission Through the fluid to the battery's cells is assessed with the aid of these models. The water's temperature as it enters the cold plate is 20 °C, and it is 27 °C when it leaves the plate. The speed of fluid is 0.5 m/s. The water's temperature differential from the entrance to the outflow is 7 °C. This shows how much heat the coolant absorbs as it moves past the cold plate. The cold plate's average temperature of 27 °C indicates that its surface effectively dissipates heat. Different pressure gradients are seen along the minichannels' length, according to the research. Lower pressures are detected at the exit and higher pressures are found near the intake, when the coolant enters the cold plate. Heat transmission is facilitated by the coolant flowing through the minichannels due to the pressure differential. All things considered, the zigzag small channel design, when combined with meticulous thermal control analysis is necessary for effective temperature regulation, which extends the life and maximizes the performance of lithium-ion batteries.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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