

Design and Analysis of a Hybrid Heat Exchanger for Electric Vehicle Batteries Using Phase Change Material (PCM) and Nanofluid Cooling

Vinay Vijay Jadhav¹, Abhijeet Ashok Patil², Akash Gokul More³, Gurfan Sheikh⁴, Mahesh C. Dhere⁵

^{1,2,3,4,5}Dept of Mechanical Engineering, Genba Sopanrao Moze College of Engineering, Balewadi

<p>Peer Review Information</p> <p><i>Type: Article</i> <i>Received: 23 February 2026</i> <i>Revised: 24 March 2026</i> <i>Accepted: 22 April 2026</i> <i>Published: 20 May 2026</i></p>	<p style="text-align: center;">Abstract</p> <p>Lithium-ion batteries are widely used in electric vehicles, portable electronics, and renewable energy storage systems due to their high energy density and long cycle life. However, during charging and discharging processes, significant heat is generated inside the battery because of internal resistance and electrochemical reactions. If this heat is not properly dissipated, battery temperature can rise beyond the safe operating range, leading to reduced efficiency, accelerated degradation, and potential safety risks. To address this issue, an effective battery thermal management system (BTMS) is required. In this study, a hybrid cooling approach combining phase change material (PCM) and a heat exchanger is proposed to control battery temperature. The PCM absorbs heat generated by the battery through latent heat storage, while the heat exchanger removes accumulated heat using circulating fluid. Computational Fluid Dynamics (CFD) analysis was conducted to evaluate temperature distribution, heat flux, and cooling performance of the proposed system. Simulation results indicate that the hybrid cooling system significantly reduces the maximum battery temperature and improves thermal stability. The proposed approach demonstrates potential for improving battery efficiency, safety, and operational life.</p> <p>Keywords: Battery Thermal Management System; Lithium-Ion Battery; Phase Change Material; Heat Exchanger; CFD Analysis; Thermal Control.</p>
--	---

How to Cite This Article

Jadhav, V. V., Patil, A. A., More, A. G., Sheikh, G., & Dhere, M. C. (2026). *Design and analysis of a hybrid heat exchanger for electric vehicle batteries using phase change material (PCM) and nanofluid cooling. International Journal on Advanced Computer Theory and Engineering, 15(2s), 333–337.*

Introduction

Lithium-ion batteries have become an essential component in modern energy storage systems, particularly in electric vehicles, consumer electronics, and renewable energy applications. These batteries provide high energy density, lightweight design, and long cycle life compared to traditional energy storage technologies. However, one of the major challenges associated with lithium-ion batteries is heat generation during operation.

During charging and discharging processes, internal electrochemical reactions and electrical resistance generate heat inside the battery. If this heat is not effectively dissipated, battery temperature can increase significantly. Elevated temperatures may lead to reduced battery efficiency, capacity loss, accelerated aging, and in extreme cases, thermal runaway.

Previous research has shown that lithium-ion batteries operate most efficiently within a temperature range of approximately 15°C to 35°C . When battery temperature exceeds this range, the internal resistance increases and the rate of chemical degradation accelerates. Therefore, maintaining the battery within the optimal temperature range is critical for ensuring safe and efficient operation.

Battery Thermal Management Systems (BTMS) are designed to control battery temperature and maintain thermal uniformity across battery cells. Various cooling methods have been developed, including air cooling, liquid cooling, and phase change material (PCM) cooling. Among these techniques, PCM-based cooling systems have gained attention due to their high heat absorption capability through latent heat storage.

This research proposes a hybrid battery cooling system that integrates PCM with a heat exchanger. The PCM absorbs heat generated by the battery, while the heat exchanger removes the stored heat using a circulating cooling fluid. The aim of this study is to evaluate the thermal performance of the proposed system through CFD simulation.

Literature Review

Several studies have investigated thermal management techniques for lithium-ion batteries to improve performance and safety. Researchers have identified temperature control as a critical factor affecting battery efficiency and lifespan.

Khateeb et al. demonstrated that phase change materials can effectively absorb heat generated by lithium-ion batteries, reducing peak battery temperature and maintaining thermal stability. The latent heat storage capability of PCM allows it to absorb significant thermal energy without a large increase in temperature.

Rao and Wang investigated hybrid battery cooling systems that combine PCM with liquid cooling techniques. Their research showed that hybrid systems provide better thermal control compared to single cooling methods. The PCM absorbs heat initially, while the liquid cooling system removes accumulated heat from the PCM.

Pesaran studied the importance of battery thermal management in electric vehicles and emphasized that maintaining uniform temperature distribution within battery packs improves performance and reliability.

Recent studies have also used Computational Fluid Dynamics (CFD) simulations to analyze heat transfer and temperature distribution in battery cooling systems. These simulations help evaluate the effectiveness of cooling strategies before physical implementation.

Based on the literature, integrating PCM with a heat exchanger can significantly enhance heat dissipation and maintain battery temperature within the optimal operating range.

Methodology

The proposed battery thermal management system consists of a lithium-ion battery module surrounded by phase change material and integrated with a heat exchanger system. The primary components of the system include:

Table 1. Materials and Components Used in the Hybrid Battery Thermal Management System

Component	Material
Battery	Lithium-ion cell
PCM	Paraffin wax
Heat Exchanger	Copper tube
Pump	Mini DC pump
Container	Metal or acrylic casing

During battery operation, heat generated by electrochemical reactions is transferred from the battery surface to the surrounding PCM. As the PCM absorbs heat, it undergoes a phase transition from solid to liquid, storing thermal energy in the form of latent heat.

Copper tubing embedded within the PCM acts as a heat exchanger. A cooling fluid circulates through the tubing using a small pump. The fluid absorbs heat from the PCM and carries it away from the system, thereby maintaining a lower temperature around the battery.

CFD simulations were performed to analyze the thermal behavior of the system. The simulation model included the battery cell, PCM layer, and copper heat exchanger tubes. Boundary conditions were applied to simulate heat generation inside the battery and fluid flow within the cooling tubes.

The CFD analysis provided the following outputs:

- Temperature contour plots
- Heat flux distribution
- Velocity vectors of cooling fluid

These results were used to evaluate the effectiveness of the proposed cooling system.

Experimental Setup

The experimental setup consists of a lithium-ion battery placed inside a container filled with paraffin wax PCM. Copper tubing is embedded inside the PCM to act as a heat exchanger. Cooling fluid circulates through the copper tube using a small pump. Heat generated by the battery is absorbed by PCM and transferred to the cooling fluid through the heat exchanger.

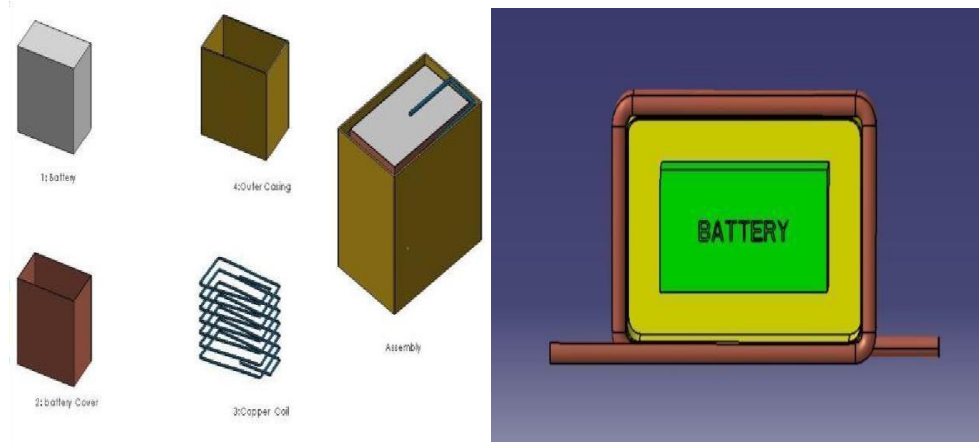


Fig. 1. Prototype of the battery cooling system.

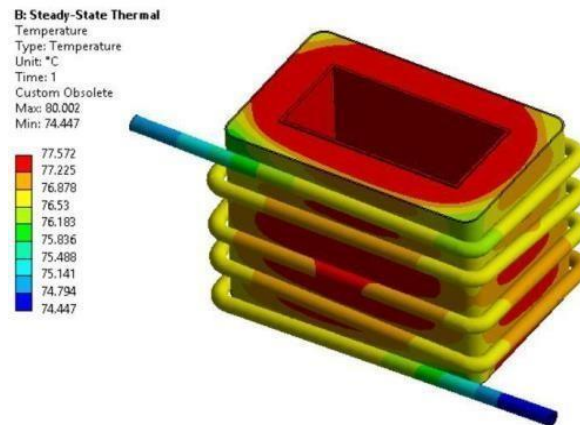


Fig. 2. Heat flux distribution inside PCM region.

CFD Observations

CFD shows the result at what temperature the work fluid is introduced and at what temperature it gets out. Here the inlet temperature is surrounding temperature (34 degree Celsius), and at outlet it becomes 48degree Celsius. This shows that the work fluid has absorbed the

heat from the model.

The model her in figure.3 shows the temperature variations and the colors indicate the range of temperature at particular location. From figure we are clear that the temperature at inlet of work fluid is less as color is blue, green and yellow. And temperature at outlet of tube is high as color indicated is red.

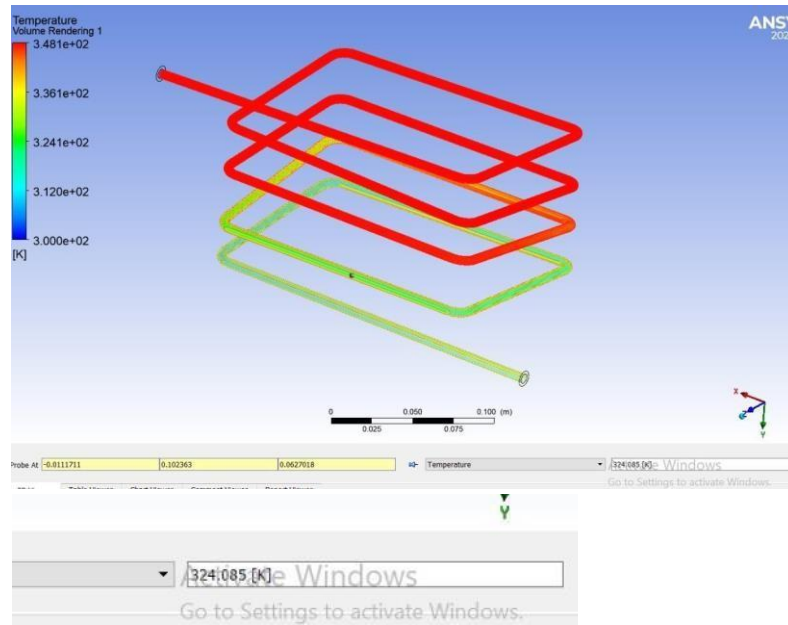


Fig. 3. Model showing Temperature variations

Table 1: CFD result observation

Sr. No.	Load	Time (Min.)	Temp. 1 Inlet of work fluid (in °C)	Temp. 2 (Temp. a t battery) (in °C)	Temp. 3 (Temp. PCM) (in °C)	Temp 4 of 4 (Outlet of Work fluid) (in °C)
1	80 °C	0	Inlet temperature considered to be room temperature 30 degree Celsius	80	73	51

Results and Discussion

The CFD analysis indicates that significant heat accumulation occurs within the battery during operation. Without any cooling mechanism, the battery temperature rises rapidly and may exceed safe operating limits.

When PCM is introduced around the battery, the rate of temperature increase is reduced due to the latent heat absorption capability of the material. The PCM absorbs the generated heat during its phase change process, which helps maintain a more stable battery temperature.

The addition of a heat exchanger further improves the thermal performance of the system. The circulating cooling fluid removes heat from the PCM and dissipates it to the surroundings. This continuous heat removal prevents excessive heat buildup in the PCM and maintains the battery temperature within the optimal range.

Temperature contour plots from the CFD simulation show a significant reduction in peak battery temperature when the hybrid cooling system is used. Heat flux diagrams also demonstrate effective heat transfer from the battery to the PCM and then to the circulating fluid.

These results confirm that the combination of PCM and heat exchanger provides an effective solution for battery thermal management.

Conclusion

Effective thermal management is essential for maintaining the performance, safety, and lifespan of lithium-ion batteries. Excessive heat generation during battery operation can lead to reduced efficiency and accelerated degradation.

This study proposed a hybrid battery thermal management system using phase change material combined with a heat exchanger. The PCM absorbs heat generated by the battery through latent heat storage, while the heat exchanger removes accumulated heat through circulating cooling fluid.

CFD simulation results demonstrate that the proposed system significantly reduces battery temperature and improves thermal stability. The hybrid cooling approach offers an efficient solution for controlling battery temperature and enhancing overall battery performance.

Future work may include experimental validation of the proposed system and optimization of PCM materials and heat exchanger design for improved cooling efficiency.

References

1. A. A. Pesaran, "Battery thermal management in EVs and HEVs: Issues and solutions,"
2. *Advanced Automotive Battery Conference*, 2001.
3. S. A. Khateeb, M. M. Farid, J. R. Selman, and S. Al-Hallaj, "Design and simulation of a lithium-ion battery with a phase change material thermal management system," *Journal of Power Sources*, vol. 128, pp. 292–307, 2004.
4. Z. Rao and S. Wang, "A review of power battery thermal energy management," *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 4554–4571, 2011.
5. S. Al-Hallaj and J. R. Selman, "Thermal modeling of secondary lithium batteries for electric vehicle/hybrid electric vehicle applications," *Journal of Power Sources*, vol. 110, pp. 341– 348, 2002.
6. J. Jaguemont, L. Boulon, and Y. Dubé, "A comprehensive review of lithium-ion batteries used in hybrid and electric vehicles at cold temperatures," *Applied Energy*, vol. 164, pp. 99– 114, 2016.