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Battery Thermal Management System Using Phase Change Materials

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Abstract: This research paper explores the integration of Phase Change Materials (PCMs) into Electric Vehicle (EV) battery packs for enhanced thermal management. Through a comprehensive study involving design, simulation, and analysis using tools like ANSYS, the effectiveness of PCM integration in managing temperature profiles and heat dissipation within EV battery packs is evaluated. The research highlights the advantages of PCM-based thermal management over traditional air and water cooling methods, emphasizing improvements in battery performance, lifespan, and overall safety. The findings contribute valuable insights to advancing EV technology and sustainability, paving the way for more efficient and reliable electric mobility solutions.
Keywords: Phase Change Materials (PCMs), Electric Vehicle (EV), Thermal Management, Battery Pack

I. INTRODUCTION

The rapid global transition towards electric vehicles (EVs) as a sustainable transportation solution has necessitated advancements in battery technology and thermal management systems. Central to this evolution is the effective cooling of EV battery packs, crucial for ensuring optimal performance, longevity, and safety of the energy storage system. Traditional air or liquid cooling methods, while effective to some extent, face challenges in managing the increasingly high heat generation rates of modern lithium-ion batteries used in EVs. As such, there arises a compelling need for innovative thermal management solutions to address these challenges and unlock the full potential of EVs.

One such promising solution is the integration of Phase Change Materials (PCMs) into the battery pack's thermal management system. PCMs are materials capable of storing and releasing large amounts of thermal energy during phase transitions, such as solid-to-liquid or liquid-to-gas, while maintaining nearly constant temperature. This unique property makes them ideal candidates for passive thermal regulation, offering efficient heat absorption and dissipation capabilities within a specified temperature range. Fig 1 shows effects of temperature on battery's life.

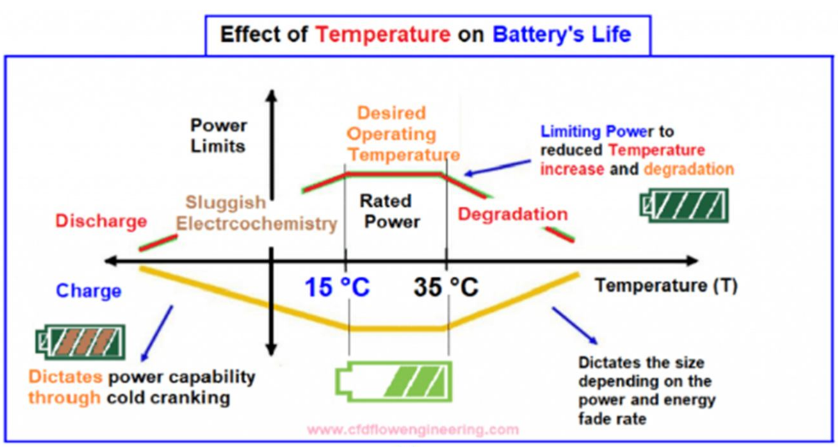

Fig.1 Effect of temperature on battery's life

The integration of PCMs within EV battery packs aims to mitigate thermal fluctuations, prevent overheating, and enhance overall battery performance and lifespan. By strategically placing PCMs in close proximity to battery cells or modules, heat generated during charging, discharging, or high-demand driving scenarios can be absorbed and stored by the PCM. Subsequently, during periods of low heat generation or when ambient temperatures rise, the stored thermal energy is released, aiding in cooling and maintaining the battery within optimal operating conditions.

This research paper delves into the design, analysis, and performance evaluation of an EV battery pack integrated with PCM-based thermal management. Utilizing advanced simulation tools such as ANSYS, detailed thermal analyses are conducted to assess the effectiveness of PCM integration in managing temperature profiles, heat dissipation rates, and overall thermal stability of the battery pack. The findings from this study contribute to the ongoing efforts in developing robust and efficient thermal management strategies for next-generation EVs, fostering their widespread adoption and environmental sustainability

II. METHODOLGY

A. *Use of Phase Change Materials*

Phase Change Materials (PCMs) offer a compelling alternative to traditional air and water cooling methods in the context of electric vehicles (EVs), presenting unique advantages that address critical challenges in battery thermal management.

Firstly, compared to air cooling, PCM-based systems provide superior heat absorption and dissipation capabilities. Air cooling relies on external airflow to carry away heat, which can be limited by factors such as vehicle speed, ambient temperature, and aerodynamic design. In contrast, PCMs can store and release large amounts of thermal energy during phase transitions, offering a passive cooling mechanism that is independent of external factors. This ensures consistent and effective cooling even under varying operating conditions, reducing the risk of overheating and thermal stress on EV battery packs.

Secondly, PCM systems outperform water cooling in terms of simplicity, reliability, and space utilization. Water cooling involves complex plumbing, pumps, and heat exchangers, which add weight, cost, and potential points of failure to the vehicle's thermal management system. PCMs, on the other hand, can be integrated directly into the battery pack or thermal interface materials, requiring minimal additional components and maintenance. This streamlined approach not only enhances reliability but also optimizes space utilization within the EV, allowing for more efficient packaging of components and maximizing onboard storage capacity.

Moreover, PCMs offer inherent safety benefits over water-based systems. Water cooling systems pose a risk of leakage or corrosion, especially in high-vibration automotive environments, potentially compromising the integrity of the battery pack and surrounding electronics. PCMs, being solid or semi-solid at typical operating temperatures, eliminate the risk of leaks and chemical interactions, contributing to overall system robustness and longevity. Frame Selection

Opting for an X-frame configuration for the agricultural drone offers benefits for efficient and effective operations. With its symmetrical design, the X-frame provides inherent stability during flight, essential for precise maneuvering and data collection in agricultural settings. The frame chosen by us for this drone is a ff450 frame made of glass fiber and polyamide nylon. Fig. 2 shows the dimensions of the drone frame..

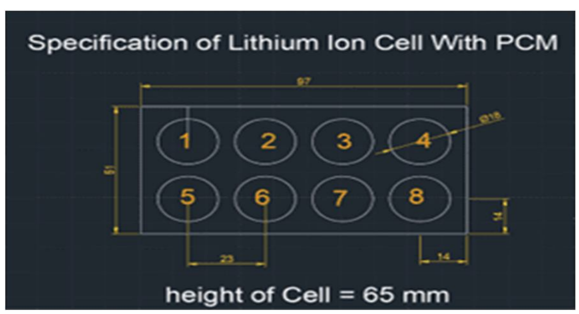

Fig. 2 Cell Specifications

B. *Cell Design and Analysis*

The cell design and analysis phase of the project focuses on creating an optimized battery pack layout and conducting thorough simulations to evaluate its thermal performance with PCM integration. Initially, the battery pack's physical design is defined, considering factors such as cell arrangement, interconnections, and PCM placement. Computer-aided design (CAD) software is utilized to create detailed 3D models, ensuring accuracy and feasibility.

Subsequently, the designed battery pack model is input into simulation tools like ANSYS for comprehensive thermal analysis. This includes assessing temperature distributions within the pack, heat transfer rates between cells and PCM elements, and overall thermal stability under different operating conditions. By simulating real-world scenarios such as charging, discharging, and high-demand driving, the effectiveness of PCM integration in managing heat dissipation and maintaining optimal battery temperatures is quantitatively evaluated. Fig. 2 shows the cell specifications.

The cell design and analysis phase culminates in generating detailed insights and data on the thermal behavior of the battery pack with PCM integration. These findings are crucial for informing subsequent stages of the project, such as interpreting results, drawing conclusions, and ultimately, contributing to the research paper's comprehensive discussion on enhancing EV battery thermal management

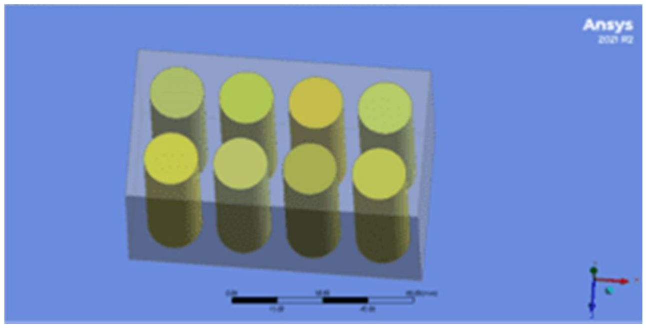

Fig. 3 cells

Details View

Details of Cell	
Part	Cell
Volume	1.3232e+05 mm³
Surface Area	33477 mm²
Bodies	8
Faces	24
Edges	16
Vertices	0
Fluid/Solid	Solid
Shared Topology Method	Automatic

Fig.4 Details of Cell

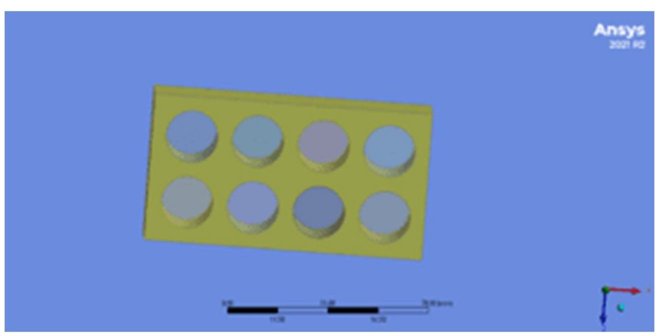

Fig. 5 Pcm material

Details of Body	
Body	PCM
Volume	1.8923e+05 mm³
Surface Area	54468 mm²
Faces	14
Edges	28
Vertices	8
Fluid/Solid	Solid
Shared Topology Method	Automatic

Fig. 6 Details of battery body

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III.RESULTS AND DISCUSSION

A. Properties of Cell and PCM

1) CELL

Cell Type: Li-ion.
Density: 2604.92 kg/m3.
Specific Heat: 894 KJ/Kg.K
Thermal Conductivity: 1.035 W/m.K
Current Capacity: 3.6 Ah
Voltage: 3.6 V

2) PCM

Material: N-Octadecane
Specific heat: 2180 J/Kg.K
Thermal Conductivity: 0.15 W/m.K
Viscosity: 0.35 kg/m.s

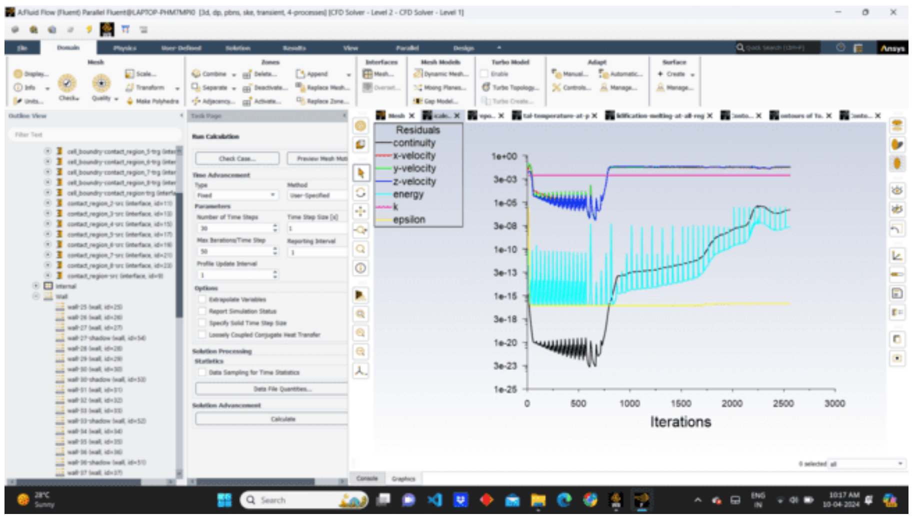

Fig. 6

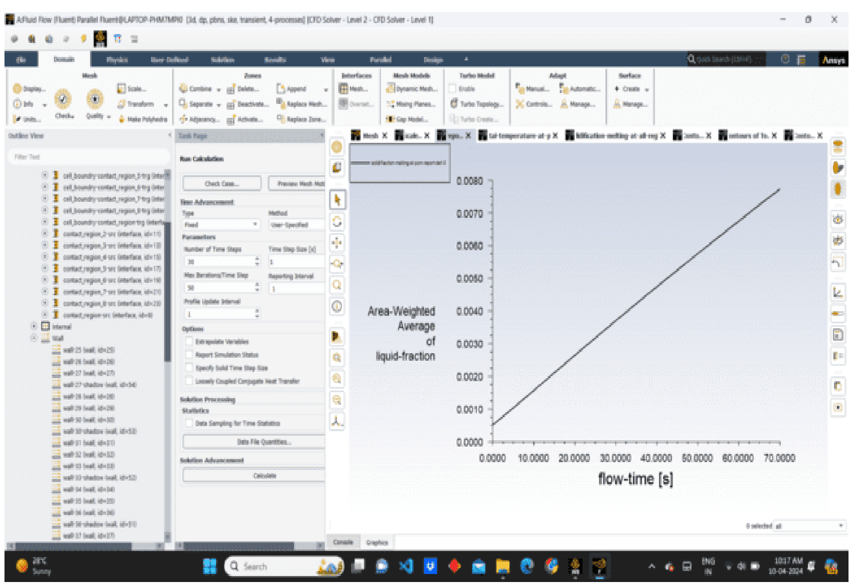

Fig. 7 Area weighted average of liquid fraction

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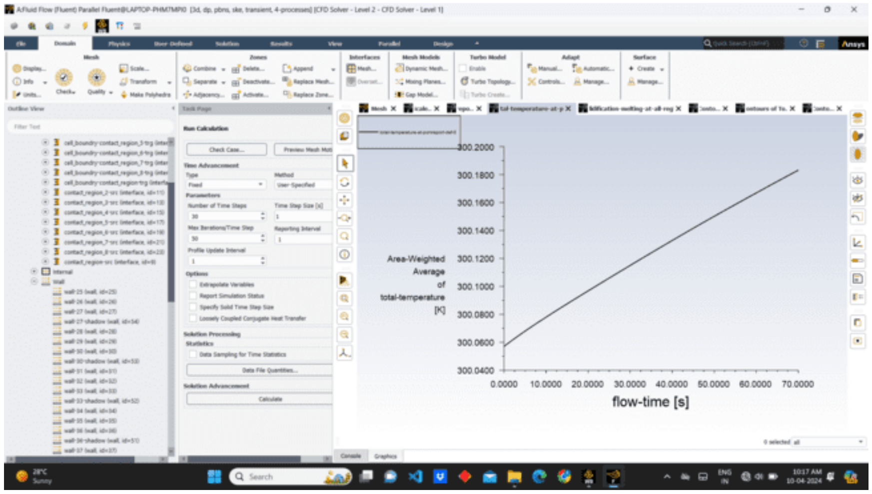

Fig. 8 Area weighted average of total temperature

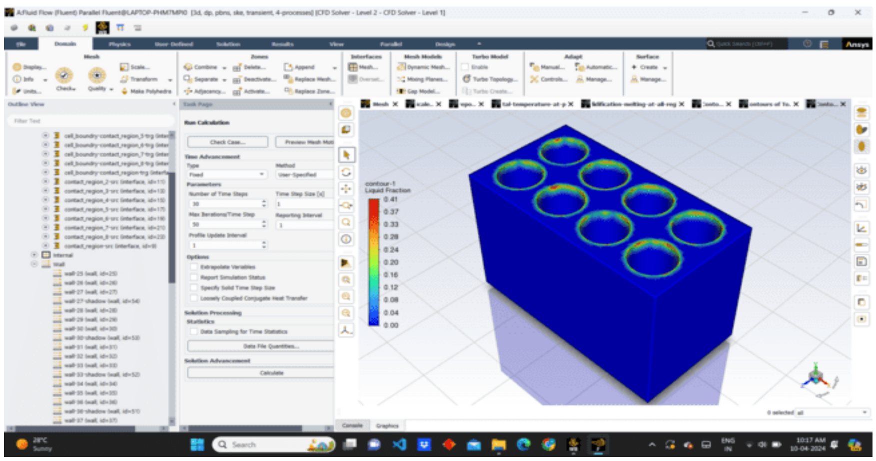

Fig. 9 liquid fraction

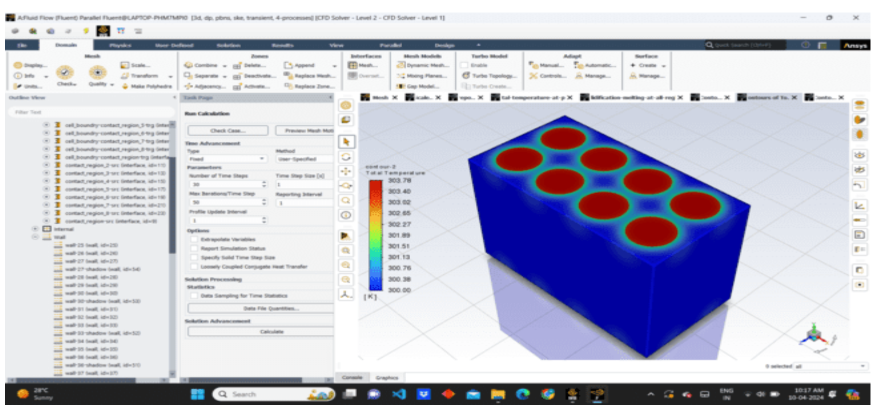

Fig. 10 Total temperature

PCM
Material: N-paraffin
Specific heat: 2100 J/Kg.K
Thermal Conductivity: 0.21 W/m.K
Viscosity: 0.003 kg/m.s

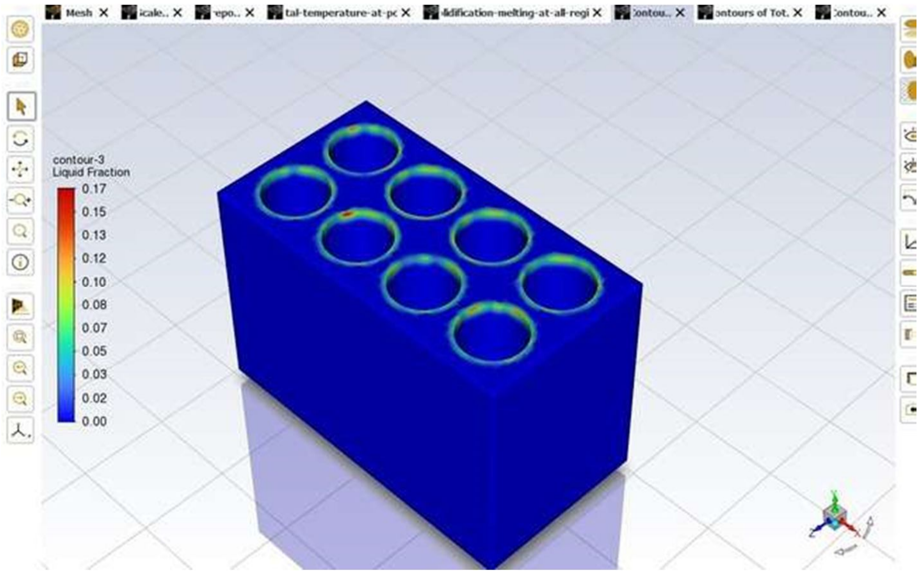

Fig. 11 Liquid Fraction

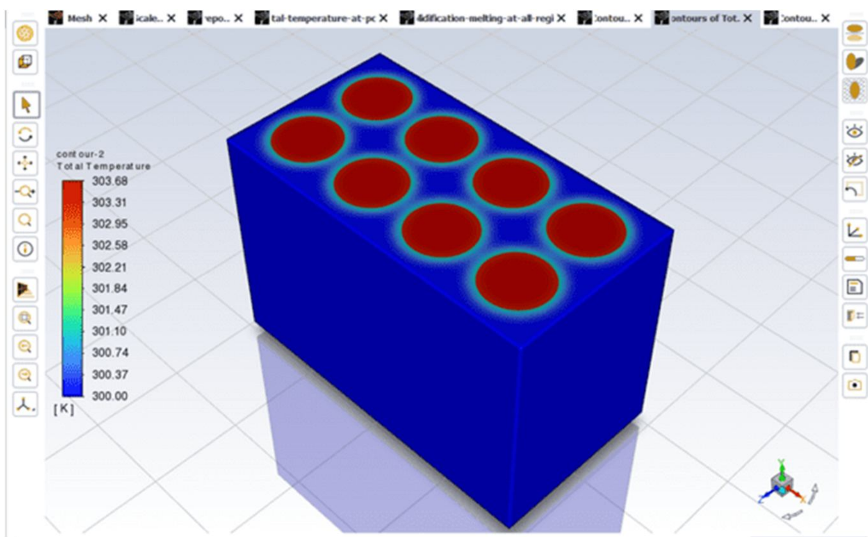

Fig. 12 Total temperature

IV. CONCLUSIONS

In conclusion, the integration of Phase Change Materials (PCMs) into Electric Vehicle (EV) battery packs for thermal management shows significant promise in enhancing overall performance and longevity. Through comprehensive design, simulation, and analysis, this research underscores the effectiveness of PCM integration in managing temperature fluctuations, improving heat dissipation, and ensuring optimal operating conditions for EV batteries. The findings contribute valuable insights to the ongoing efforts in advancing EV technology, emphasizing the importance of innovative thermal management solutions like PCM integration for sustainable and efficient electric mobility. Future research can further refine PCM configurations and explore novel materials to continue pushing the boundaries of EV battery thermal management. Furthermore, the successful implementation of PCM-based thermal management systems not only enhances battery performance but also contributes significantly to the broader goals of environmental sustainability and energy efficiency. By effectively managing heat within EV battery packs, PCM integration reduces the risk of thermal runaway events, prolongs battery lifespan, and ultimately promotes safer and more reliable electric vehicles. This holistic approach aligns with the global transition towards cleaner transportation solutions and reinforces the role of advanced materials and technologies in shaping the future of mobility. Continued innovation and collaboration across industries will drive further advancements in PCM applications, fostering a greener and more sustainable automotive landscape.

V. ACKNOWLEDGMENT

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