Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Thermal Management of Batteries Using Composite PCMs and Active Refrigerant Cooling

Safayet Mahmud[1*], Antonio Bertuccio[1], Ofelia A. Jianu[1]
[1]Department of Mechanical, Automotive & Materials Engineering, University of Windsor, Windsor, Canada
*mahmud84@uwindsor.ca

Abstract

Battery thermal management systems (BTMS) are critical for maintaining the optimal performance, longevity, and safety of batteries, especially in electric vehicles (EVs) and energy storage systems. Effective thermal management ensures that batteries operate within the desired temperature range, preventing issues such as thermal runaway, decreased efficiency, and reduced lifespan. Phase change materials (PCMs) have emerged as a promising solution for BTMS due to their ability to absorb and release large amounts of heat during phase transitions.

This research focuses on designing a hybrid active cooling BTMS that integrates composite PCMs with a refrigerant loop for effective thermal regulation. The hybrid system incorporates a serpentine copper tubing design embedded within composite PCMs to maximize thermal performance. The composite PCMs are engineered to absorb and store heat during peak thermal loads, leveraging their high latent heat capacity and enhanced thermal conductivity. Simultaneously, the active refrigerant loop operates as a dynamic cooling mechanism, ensuring that the battery module remains within the optimal temperature range during extended high-power operations. This combination of passive and active cooling methods aims to achieve a uniform temperature distribution while mitigating localized overheating.

The system was modeled in ANSYS Fluent using a Samsung SDI 131Ah lithium-ion battery to evaluate its thermal performance under varying load conditions. The hybrid design integrates a serpentine copper tubing geometry embedded within composite PCMs, effectively balancing high thermal conductivity with substantial latent heat storage capacity. The composite PCMs absorb excess heat during peak thermal loads, ensuring temperature uniformity across the battery module. Simultaneously, the active refrigerant loop operates in synergy with the PCMs, dynamically extracting heat and maintaining the battery within optimal operating temperatures.

Simulations were conducted under discharge rates ranging from 1C to 5C (in increments of 1C) and ambient temperatures from 20°C to 45°C. The numerical results show that the hybrid BTMS reduces peak battery temperatures by 12.5°C compared to conventional air-cooled systems. The serpentine tubing achieves localized heat transfer rates of 1506.62 $W/m^2{\cdot}K$, while the refrigerant flow operates at a Reynolds number of approximately 13810, ensuring turbulent flow and efficient cooling. Exergy analysis reveals a 15% improvement in the thermal efficiency of overactive-only systems. Results show that under peak loads, the hybrid system maintains battery temperatures below 38°C, compared to 50.5°C without PCMs.