PCM-Based Thermal Energy Storage for Thermal Management of Heavy-Duty Batteries

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Abstract

Thermal management is critical for ensuring performance, safety, and durability in heavy-duty vehicles (HDVs) battery systems, which experience high thermal loads during operation. This study experimentally investigates a phase change material (PCM)-based thermal energy storage (TES) system as a passive solution for battery thermal management (BTM). Five commercial PCMs were thermally characterized through differential scanning calorimetry (DSC), thermal conductivity measurements, and cycling stability tests.
N-octadecane emerged as the most suitable candidate, exhibiting a melting range of 25–32 °C, high latent heat (≈222 J g^{-1}), and excellent thermal durability over 20 cycles. A dedicated fin-and-tube TES system filled with n-octadecane was tested under various heat-transfer-fluid (HTF) flow rates (2–3 L min^{-1}). Results showed that heat transfer was conduction-dominated in the solid state and strongly convection-enhanced in the liquid state. While HTF flow rate had limited impact on total charging/discharging times, it significantly improved thermal power output. At 3 L min^{-1}, the TES achieved a thermal power ratio of 56, alongside substantial performance gains compared to the no-PCM baseline: a 3.5× increase in gravimetric specific power (0.056 kW kg^{-1}) and a 6× increase in volumetric specific power (approximately 68 kW m^{-3}). Overall, the findings validate n-octadecane as a promising PCM for passive thermal buffering in HDV battery systems and highlight the potential of modular PCM-TES units as scalable solutions for battery pack cooling or cabin thermal management.

Keywords: ModVal2026, phase change material, battery thermal management, thermal characterization, thermal energy storage.