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Development of a Module-Level EV Thermal Management System Through CFD Analysis to Enhance Cold-Start Performance in 21700 Lithium-Ion Batteries

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ABSTRACT

This research focuses on enhancing the thermal management system of a 21700 lithium-ion battery module used in cargo vans. Currently, it takes approximately 20 minutes for the module to reach its optimal operating temperature under sub-zero temperatures, which impacts the cell lifespan during cold starts. Efficient thermal management is crucial for maintaining battery longevity in electric vehicles (EVs), especially in sub-zero temperatures.

A hybrid thermal management system that integrates conventional liquid cooling with electrical resistance heating elements to improve thermal efficiency and reduce warm-up time is proposed. While liquid cooling is traditionally used for temperature regulation during operation, this study examines its role in thermal stabilization under cold conditions. Simultaneously, electrical resistance heating elements are assessed for providing rapid, localized heating to minimize thermal lag and temperature gradients.

To evaluate the proposed thermal management system, CFD simulations are conducted on a 21700 lithium-ion battery module consisting of 260 cylindrical cells connected in a 10s26p configuration and discharged at a 0.2 C-rate under -20°C ambient conditions. The module is mounted above a cold plate cooled by a 50/50 water-glycol mixture modeled as a single-phase coolant, with turbulence effects represented using simplified assumptions suitable for system-level analysis. Heat generation is modeled using the Batemo Cell Model FMU to ensure accurate electrothermal coupling. Electrical heating plates are incorporated using a constant temperature boundary condition with uniform heat distribution, and their placement is varied to evaluate the impact of different configurations on thermal performance. Validation is carried out through comparison with existing literature. Expected outcomes include reduced warm-up time, improved temperature uniformity, and increased energy efficiency, with the overall objective of bringing cell temperatures into the optimal operating range of 10°C to 30°C.

Overall, this study provides valuable insights into hybrid heating strategies for next-generation EV battery thermal management systems. By optimizing heat distribution and reducing warm-up time, the proposed solution contributes to reliable EV operation, supporting the broader adoption of electric mobility in cold climates. Additionally, it establishes a foundation for future advancements in integrated thermal management systems, which could be applied to a wider range of EVs.