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ABSTRACT:

Constructal Design of a Phase Change Material Reservoir with Fins for Thermal Management of Lithium-Ion Battery Packs

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Constructal Theory is a multidisciplinary framework that supports the idea that the configuration and evolution of a flow system (animate or inanimate) do not occur randomly, but rather follow a physical principle known as the constructal law. In the constructal realm, evolution over time represents the change in design of a system that can freely morph, including engineering systems, where the constructal design method (CDM) is applied. The CDM guides the designer toward flow architectures that achieve higher global performance for a specified flow (e.g., fluid flow, heat flow, and others). In engineering applications, this method has been widely employed to study the geometry of finite-size flow systems, such as cooling systems for lithium-ion (Li-ion) battery packs. In this context, the present work investigates a battery thermal management system (BTMS) that uses a phase change material (PCM) reservoir with Y-shaped fins through the lens of constructal design. The influence of the number of fins and their aspect ratio on the battery temperature under a 5C discharge rate is explored. The fixed geometric parameter is the ratio between the PCM area and the area occupied by the fins (φ), while the degrees of freedom are the number and geometry of the Y-shaped fins. The proposed problem is addressed numerically using the finite volume method, solving the conservation equations of mass, momentum, and energy, along with the enthalpy-porosity model to describe PCM melting. The results indicate that both the number of fins and their aspect ratio significantly influence the PCM melting behavior and, consequently, the battery cooling performance. The maximum temperature reached by
the battery is substantially lower for the finned reservoir compared to the finless configuration, which serves as the baseline geometry.

Keywords: Constructal Design. Lithium-Ion Battery. Battery Pack Temperature. Battery Cooling. Thermal Runaway.