A Multi-Scale Framework for Holistic Prismatic Battery Thermal Management: Coupling Internal Dynamics with External Regulation

Dr. Ekta Singh Shrinet[1], Dr. Williams Agyei Appiah[1]
[1]University Of Agder, , Norway

Electrochemical heat generation in lithium-ion batteries is inherently non-uniform and strongly governed by internal states such as reaction current density and overpotential. Conventional battery thermal management systems rely on temperature-based control with uniform cooling, often leading to overdesign, excessive pumping power, and persistent thermal gradients. In this work, a spatially resolved electrochemical–thermal framework is developed by coupling a P2D model with a two-dimensional heat transfer model for prismatic cells. In addition, internal electrolyte channel geometries are incorporated to investigate their influence on coupled transport and heat generation behavior.

The model captures spatial and temporal heat generation and shows how electrolyte channels affect ion transport, reaction distribution, and temperature. Based on these electrochemical insights, an adaptive cooling strategy is proposed in which the local coolant flow rate is dynamically regulated as a function of spatial heat generation and temperature gradients. This approach enables targeted cooling in regions with high thermal activity while maintaining minimal baseline flow elsewhere. The cooling boundary condition is further linked to flow-dependent convective heat transfer, allowing realistic estimation of thermal response and pumping requirements.

The framework is evaluated under different channel configurations using key metrics including maximum temperature, temperature uniformity, and pumping power. Results demonstrate that electrolyte channel design improves transport uniformity and, when combined with adaptive cooling, significantly reduces peak temperature and intra-cell thermal gradients while lowering overall pumping power. The study highlights the potential of integrating electrochemical modeling with geometric design for thermal management of next-generation lithium-ion batteries.