Topology-Optimized Battery Cold Plate Design Based on COMSOL and MATLAB

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This study presents a topology optimization framework for battery cold plates using COMSOL and MATLAB. By coupling turbulent flow and heat transfer models, four key parameters are parametrically analyzed. A Kriging surrogate model and NSGA-II algorithm are employed to balance heat dissipation and flow resistance. The framework requires only 81 samples for high accuracy, achieving a 925-fold efficiency improvement. The optimized design reduces maximum temperature by 1.5 K and pressure drop by 87.49% compared to traditional channels.

Abstract

Thermal runaway risks in lithium-ion batteries demand efficient liquid cooling. However, traditional channel designs struggle to simultaneously achieve high heat dissipation and low flow resistance within constrained spaces. This research addresses this bottleneck by replacing empirical designs with a data-driven topology optimization approach. We utilize the density method to couple turbulent flow and heat transfer physics. Four critical parameters—Darcy penalization, projection slope, coolant volume fraction, and thermal-hydraulic weight—are parameterized. COMSOL handles batch simulations, while MATLAB independently constructs a Kriging surrogate model to execute NSGA-II multi-objective optimization, effectively balancing the trade-off between thermal and hydraulic performance.

Methodology:

Developed a topology optimization model based on the density method, coupling turbulent flow and heat transfer for thermal-hydraulic design.

Four key parameters (Darcy penalization factor, projection slope, coolant volume fraction, thermal-hydraulic weight) were utilized to establish a multi-objective optimization framework.

Executed batch simulations in COMSOL, independently constructed a Kriging surrogate model in MATLAB, and applied the NSGA-II algorithm for multi-objective optimization.

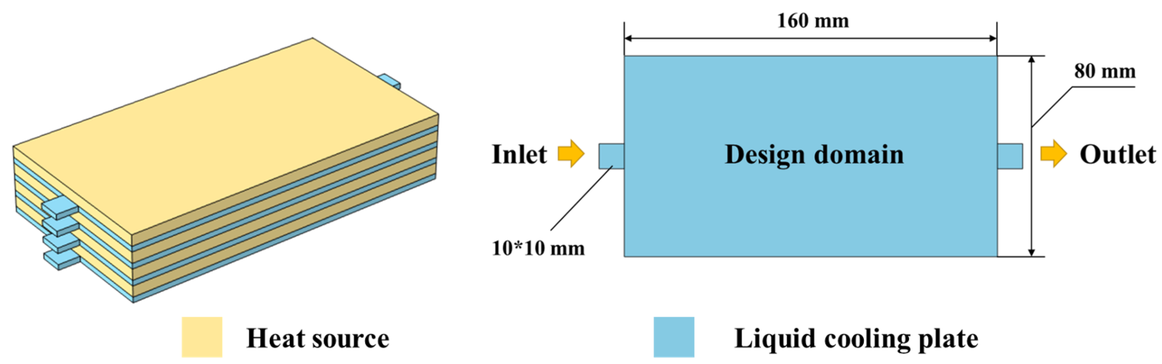


Fig. 1. Schematic diagram of the topology design domain for the liquid-cooled plate.

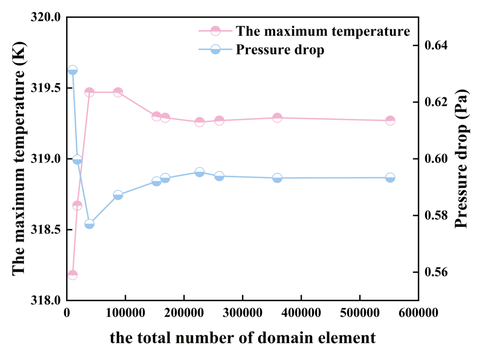


Fig. 2. Grid independence analysis.

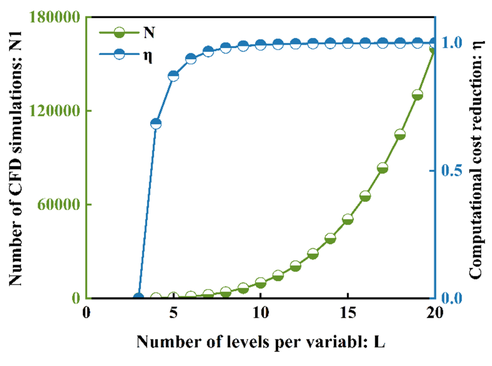


Fig. 3. Full factorial simulation count and efficiency improvement factor as functions of the number of parameter levels.

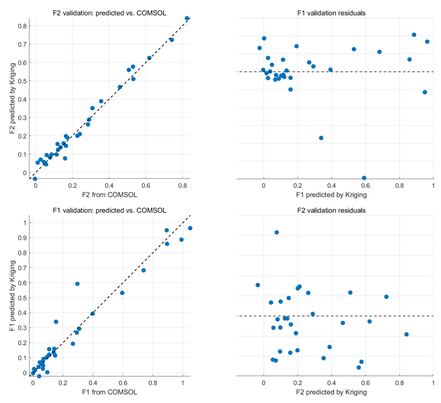


Fig.4. Validation of the Kriging surrogate model.

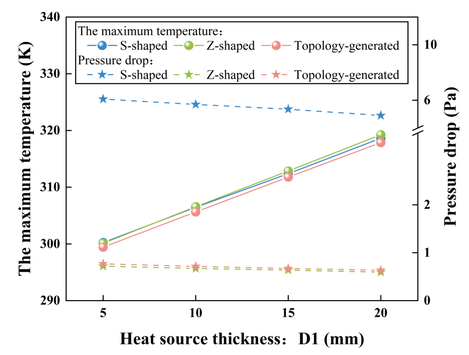


Fig.5. Temperature drop performance comparison

Results

- Efficiency: Only 81 samples needed versus 75,000 for full factorial design, achieving a 925-fold speedup.
- Thermal Performance: 1.5 K lower maximum temperature versus a Z-shaped channel; 87.49% lower pressure drop and 0.8 K lower temperature compared to an S-shaped serpentine channel.
- Model and Algorithm: Kriging model achieves R^2 of 0.998 with concentrated residuals; NSGA-II shows rapid convergence and a uniform Pareto front.

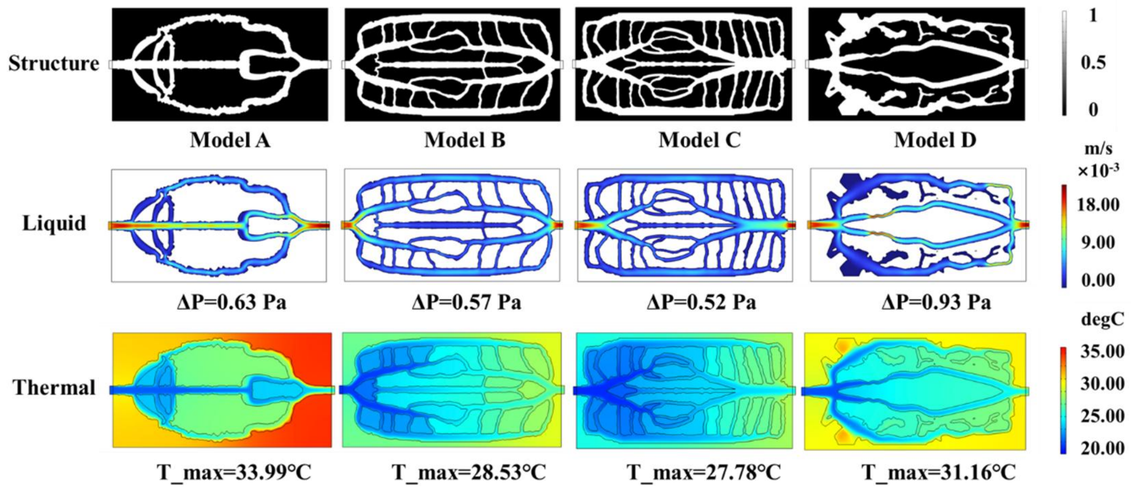


Fig. 6. Topological configurations, flow fields, and temperature fields corresponding to Models A, B, C, and D.

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