# ABSTRACT

The continued miniaturization of electronic and electrochemical devices has significantly intensified the challenge of effective thermal management under highly confined conditions. Micro- and mini-scale confinement-based cooling strategies have therefore attracted considerable attention due to their ability to enhance heat transfer within compact systems. However, at reduced length scales, thermo-fluid transport is no longer governed solely by bulk fluid properties or geometric parameters. Instead, near-wall transport mechanisms, fluid rheology, and interfacial effects dominate, leading to complex, strongly coupled transport behaviour in confined systems.

The present thesis develops a unified multiscale framework that links confinement geometry, fluid rheology, and interfacial effects to investigate their coupled influence on heat transfer and flow characteristics in micro- and mini-scale confinements. A systematic combination of numerical simulations, experimental investigations, and analytical modelling is employed to elucidate the underlying physical mechanisms governing near-wall transport, flow distribution, and thermohydraulic performance. The study reveals that variations in confinement design, rheological behaviour, and surface properties can significantly alter transport dynamics, leading to nontrivial interactions that directly affect overall thermal and hydraulic performance. The developed framework is further extended to application-scale thermal management systems, including battery-cooling configurations, to demonstrate the scalability and practical relevance of confined transport principles. The results show that confinement-based design strategies can effectively suppress thermal non-uniformities and improve temperature regulation in compact systems. Overall, this thesis provides physics-based insights and design guidelines for developing efficient, scalable, and manufacturable thermal management solutions while maintaining an appropriate balance between thermal performance and hydraulic efficiency.

**Keywords:** Confined thermofluid transport, interfacial effects, fluid rheology, micro- and mini-scale systems, thermal management.