

ON OPTIMIZING THE TOPOGRAPHY OF FLAT HEAT PIPES

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Abstract

The performance of flat micro heat pipes (FMHPs) depends strongly on the interaction between thermal conduction, capillary-driven liquid transport, vapor flow, and phase change. As modern electronic devices continue to shrink while operating at higher heat fluxes, the internal wick geometry of FMHPs plays an increasingly important role in determining their overall efficiency. Conventional design practices rely either on analytical models with restrictive assumptions or on parameter sweeps that explore only limited regions of the design space. In this work, a reduced-dimension numerical model is developed for FMHPs and coupled with gradient-based optimization to investigate how gradient based optimization methods can improve wick distribution and overall thermal performance.

The model represents the coupled thermal and hydrodynamic behavior in three interacting layers: the solid wall, the liquid-saturated porous wick, and the vapor core. Heat transfer in the wall is described through a two-dimensional steady-state conduction model with external heating and convective cooling. Liquid transport is modeled using the Navier-Stokes-Brinkman formulation, which allows viscous effects to be represented beyond what is captured by Darcy's law. The vapor domain is treated as a weakly compressible, saturated flow modeled by a reduced form of the Navier–Stokes equations. Temperature and pressure in the vapor are related through the Clausius–Clapeyron equation, allowing the working temperature to adjust consistently with the imposed heat flux. Phase change is included through a source term that couples the vapor and wick domains and is compatible with the spatially varying wick height.

The optimization problem aims to minimize viscous dissipation in both the liquid and vapor domains for a prescribed thermal load. This objective is motivated by the role of dissipation in determining the pressure losses that must be supported by capillary forces within the wick. A weighted sum formulation allows the relative influence of liquid and vapor dissipation to be adjusted. Constraints include among others a limit on local superheat to avoid premature onset of boiling in the wick and a capillary pressure constraint to prevent evaporator dry-out. Wick height is treated as a

continuous design field and regularized by a PDE filter to enforce smooth spatial variation.

The optimized wick distributions produced by the method adapt to local thermal and hydrodynamic conditions in ways that differ from traditional uniform-wick layouts. For single heat-source configurations results yield combinations of full-height and intermediate-height wick regions that support low-resistance pathways for both fluid phases, thereby reducing dissipation and thermal resistance. When multiple heat sources are present, the optimized structures redistribute wick material to balance competing flow requirements and make effective use of combined evaporation areas.

Overall, the study shows that gradient-based optimization of FMHPs offers a systematic approach for synthesizing wick designs beyond those typically considered.