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On the hydrostatic limit for thin film flow -- applications to thermosyphons

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ABSTRACT

The efficacy of a heat pipe is, in many cases, limited by its ability to return, via capillary pumping, liquid produced in the condenser section to the evaporator section. When the heat pipe wick is removed or the heat pipe is overfilled so that its wick becomes flooded, capillary pumping becomes irrelevant. We refer, in this case, to a thermosyphon; in a close-to-horizontal orientation, the driving force for liquid return derives from a difference of liquid pool depth between the evaporator and the condenser. Increasing the depth of condensed liquid increases the driving force for flow. However, a deep pool of liquid in the condenser also limits radial heat transfer and therefore heat rejection. Thus, a balance must be struck that favors liquid pools of intermediate depth. Increasing the fill ratio above the optimized value results in an increase in manufacturing costs as well as adverse effects on performance. Using a theoretical approach, and starting from a lubrication approximation to the Navier-Stokes equations, we determine the associated performance-maximizing fill ratio and show how this ratio varies with e.g. the axial temperature difference along the thermosyphon. Our analysis avoids a common simplification, i.e. conventional descriptions of thermosyphons do not capture the incremental flow resistance due to axial variations in the liquid film thickness. This omission can result in inaccuracies when estimating the axial heat flux.

In a separate but related effort on heat pipe design and optimization, we have developed a Matlab- based, GUI-driven algorithm to predict the thermodynamic performance of a heat pipe relative to limiting conditions imposed by viscosity, capillary, entrainment, boiling and compressibility. The standalone tool aids in selecting the appropriate heat pipe working fluid and in constructing a heat pipe fundamental diagram over a wide temperature range. The tool also helps to identify optimal design parameters in a given setting.

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