Proceedings of the 11th International Conference on Fluid Flow, Heat and Mass Transfer (FFHMT 2024)
Chestnut Conference Centre - University of Toronto, Toronto, Canada – June 16-18, 2024
Paper No. 103
DOI: 10.11159/ffhmt24.103

Thermal Performance of a Two-Phase Loop Thermosyphon with a LPBF Evaporator

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Extended Abstract

Loop thermosyphons are two-phase devices that provide effective heat transport completely passively and with relatively low temperature differences between heat source and heat sink. Extensive studies have been conducted to investigate the thermal performance and stability of thermosyphons [1], [2], [3] for different filling volumes and working fluids [4]. Evaporator design has been shown to be crucial to thermosyphon performance [5], [6], [7]. To improve the performance of the thermosyphon, the surface topology of the evaporator can be modified using additive manufacturing (AM) to leverage unique design freedoms and create geometries with high specific surface areas.

To date, only Mohseni-Gharyehsafa et al. [5] have presented a thermosyphon produced entirely using AM. They described a stainless-steel single-unit device by laser powder bed fusion (LPBF), which includes a helical heat exchanger in the condenser section and pillar arrays in the evaporator section. To assess its performance, acetone was used as a working fluid and tested at different filling ratios. They found that a lower thermal resistance was achieved at the minimum filling ratio and low thermal powers. Elkholy et al. [6], [7] developed a loop thermosyphon with an aluminum LPBF mini-channel evaporator and compared its performance to a conventionally machined aluminum evaporator in natural [6] and forced [7] convection modes of a radial finned condenser. They reported that the AM evaporator achieved better evaporator performance and lower overall resistances if compared to the machined sample [7]. The AM evaporator also reduced temperature and pressure variations, which leads to more stable cooling system performance. However, this study did not fully leverage design freedom associated with LPBF evaporators.

In the present study, three evaporator heating geometries with strut-based simple cubic geometries were designed to significantly increase convective surface area of the evaporator. These were manufactured by LPBF and investigated in a two-phase loop thermosyphon for their effect on thermal resistance at input powers from 20-200 W and different working fluids (HFE7000, Novec649, HFE7100, and ethanol). The thermosyphon consists of a side-heated evaporator into which the different evaporator designs could be mounted. The porous evaporator structures were designed with pore edge lengths of 0.8 mm, 1.2 mm, and 2.0 mm and were compared to a flat surface with no pores as the baseline. The riser and downcomers consisted of transparent nylon tubing and the riser was 432 mm long with a 7.12 mm ID. The downcomer was 680 mm long with an inner diameter of 6.15 mm. The condenser consisted of a water-cooled plate heat exchanger condenser. The evaporators were electrically heated and the thermosyphon was instrumented with thermocouples throughout to quantify thermal resistances.

Thermal performance and stability were measured using thermal resistance and the standard deviation of the evaporator wall temperature. The small-sized pore surface decreased the total thermal resistance by 61% (R_{total} = 0.118 K/W) compared to the flat surface. The medium-sized pore surface showed the lowest standard deviation of the evaporator wall temperature of 0.0246 °C. Additionally, when testing with the small-sized pore surface, HFE7000 displayed the lowest thermal resistance (0.118 K/W) due to its low boiling point; Novec649 demonstrated the lowest standard deviation (0.0319 °C). Ongoing research is focusing AM approaches to produce evaporators with optimal geometry and surface structure to reduce the overall thermal resistance and support the development of high heat flux cooling for power electronics applications.

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