Visualizing Geyser-Like Boiling in a Horizontally Oriented Annular-Wick Heat Pipe

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1. Introduction

Heat pipes are attractive for passive heat removal in advanced nuclear systems because they move high heat loads with small temperature drops and no moving parts. In horizontal layouts, start-up and transients can be disturbed by boiling instabilities that cause large temperature and pressure oscillations. Geyser boiling is well known in wickless thermosyphons and vertical devices, but it is still unclear whether similar geyser-like behavior occurs in horizontal, wick-assisted heat pipes where liquid pooling, vapor blockage, and limited capillary supply can interact [1–3]. Although visualization has helped explain two-phase mechanisms, time-resolved evidence connecting geyser-like boiling to wick design in horizontal annular-wick heat pipes remains limited [4–6]. In this work, we use a transparent horizontal annular-screen wick heat pipe with water and combine high-speed imaging with synchronized wall-temperature measurements to capture nucleation and cyclic vapor growth/collapse. We also compare the annular-screen wick to a conventional screen wick under matched geometry, orientation, and filling to isolate the role of wick architecture in instability onset.

2. Experimental setup

Figure 1 illustrates the transparent visualization facility used to study geyser-like boiling in a horizontally oriented heat pipe. The evaporator is heated with an external heating wire to supply controlled, repeatable power, while the condenser is cooled by a nitrogen heat exchanger to maintain stable condensation. A transparent viewing section near the evaporator provides direct optical access to the internal two-phase behavior. Wall temperatures are measured using K-type thermocouples distributed along the tube, and the internal pressure is monitored via a pressure transmitter connected to the evacuation/charging line. High-speed imaging with backlighting captures nucleation, bubble growth and coalescence, vapor blockage, and cyclic expulsion events. Prior to filling, the device is evacuated to reduce non-condensable gases, and water is used as the working fluid. All tests are conducted under identical geometry and horizontal orientation while comparing two wick configurations, screen and annular-screen, fabricated following the same procedure as Ref. [7]. Heat input is increased stepwise from 50 to 250 W with condenser cooling held constant (HX flow rate 100 lpm, inlet temperature ~20 °C) to ensure consistent boundary conditions during visualization.

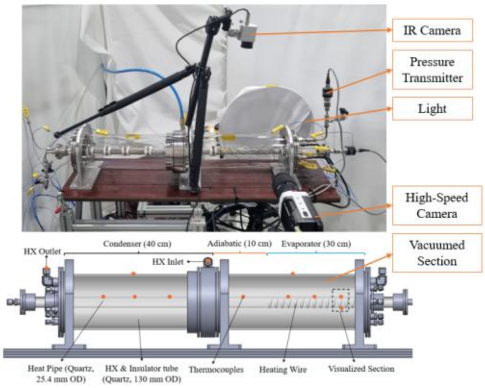

Fig. 1. Schematic of the experimental setup for visualization.

3. Results and Discussion

Figure 2 shows the screen-wick heat pipe response as power increases. After each step, wall temperatures rise and quickly reach a new quasi-steady level with no large, low-frequency oscillations.

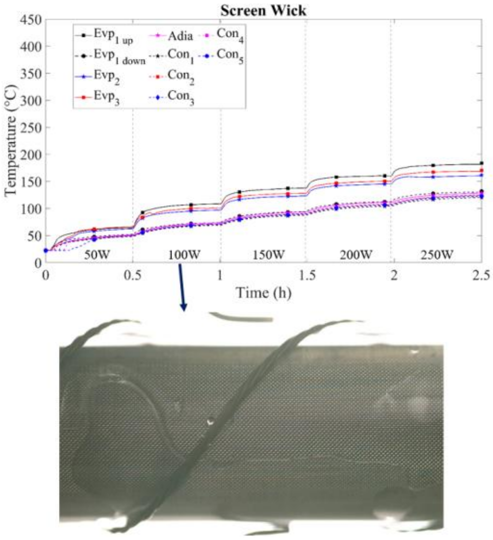

Fig. 2. Transient temperature profiles for screen wick.

This stable behavior is consistent with more continuous evaporation in the horizontal setup, likely because the screen wick maintains uniform wetting and allows vapor to escape without building a large vapor pocket.

In contrast, Figure 3 shows that the annular-wick heat pipe develops clear temperature oscillations at low-to-moderate power (≈50–100 W), marking the onset of geyser-like boiling. In this range, vapor generation is sufficient to form a large vapor pocket within the annular void space, temporarily reducing liquid–wall contact and causing a sharp temperature rise. The pocket then collapses or is expelled as it condenses in cooler regions and pressures equalize, allowing capillary rewetting and a rapid temperature drop. At higher power, the two-phase flow becomes more continuous and the oscillations weaken as operation shifts toward a steadier boiling/evaporation regime.

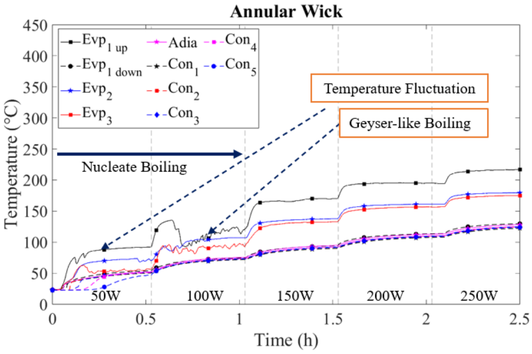

Fig. 3. Transient temperature profiles for annular wick.

Figure 4 directly supports this mechanism for the annular wick at 100 W. The images capture repeated cycles where bubbles nucleate, merge, and grow into a large vapor pocket, then collapse suddenly as the surface rewets. This shows that vapor is not removed as many small bubbles; instead it accumulates into an extended pocket, consistent with the temperature oscillations in Figure 3. The rapid collapse likely results from condensation in cooler regions and/or a sudden reopening of the flow path, which allows liquid to return and restart the cycle.

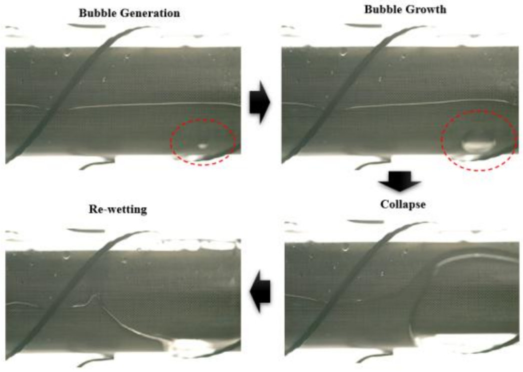

Fig. 4. Bubble generation in annular wick at 100W power input.

4. Conclusions

Geyser-like boiling in a horizontal heat pipe was studied using a transparent visualization section with synchronized temperature measurements. A screen wick and an annular-screen wick were tested under identical conditions. The screen wick showed mostly stable, stepwise temperature changes with little low-frequency oscillation, suggesting continuous evaporation and sustained wetting. The annular-screen wick exhibited strong oscillations near boiling onset (≈50–100 W), and high-speed images showed repeated growth of a large vapor pocket followed by rapid collapse and rewetting. These results indicate that annular geometry can promote vapor-pocket formation and intermittent blockage, leading to cyclic de-wetting/rewetting and stronger thermal unsteadiness.

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