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Investigation of a flat-plate oscillating heat pipe with Tesla-type check valves

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ABSTRACT

Tesla-type check valves were integrated into a flat-plate oscillating heat pipe (FP-OHP) in order to promote and sustain a desired circulatory flow to increase overall thermal performance. Using neutron radiography, gray-scale images capturing the internal flow behavior within two bottom-heated copper FP-OHPs – one with Tesla-type valves (TV FP-OHP) and one without – both charged with water at a filling ratio of 70% – were collected. With the Tesla-type valves installed in the adiabatic section of the TV FP-OHP, it was found that circulation in the desired direction was promoted and that this promotion increased with heat input. The TV FP-OHP consistently possessed a lower thermal resistance than its counterpart without check valves. The percent-reduction in thermal resistance was on-the-order of 15–25% depending on the power input. Implementation of Tesla-type check valves is a promising means for circulatory flow rectification within an OHP, but future research is needed to further optimize valve design, quantity, and alignment.

1. Introduction

With the ongoing miniaturization of electronics and their components comes the need to effectively transfer higher heat loads using novel, passive devices. The oscillating (or pulsating) heat pipe (OHP), first introduced by Akachi [1], has demonstrated to be a promising solution for future heat flux management and applications. Unlike traditional, coaxial heat pipes, the OHP is wickless, has a variety of form factors, is easier to manufacture and possesses fewer operating limitations. The OHP, as shown in Fig. 1, typically exists as a single loop, serpentine-arranged tubular structure (T-OHP) or an engraved channel on a flat plate that is sealed (FP-OHP). The OHP is partially filled with a working fluid which disperses itself into vapor and liquid volumes (a.k.a. bubbles and slugs, respectively) within the internal structure via capillary action. Heat is transferred from the evaporator to condenser via latent and sensible heat. The continual phase change of the internal working fluid results in a thermally-driven force imbalance and an ever-changing pressure field that gives rise to highly oscillatory flow patterns. Efficient operation of the OHP depends on sustaining these non-equilibrium conditions which may depend on: filling ratio, number of turns/bends, channel dimension, working fluid, operating orientation, circulation, operating temperature, and heat input. As a result, the OHP has been a topic of many investigators since its optimal design and operational characteristics are still not completely understood [2].

Since the OHP's thermal performance is coupled with its internal fluid motion, many experiments have focused on visualizing the internal flow occurring during OHP operation [3–10]. Khandekar and Groll [3] visually inspected an operating copper/glass closed-loop, single turn OHP with an inner tube diameter of 2 mm filled with ethanol. It was observed that bulk circulation occurred in an arbitrary direction and that the circulatory direction reversed intermittently until, at higher heat inputs, circulation reversal was not observed and the flow direction remained consistent. During the circulatory flow regime, fully developed annular flow occurred in the evaporator and the thermal resistance was observed to be minimal. Static phases, where internal fluid movement would cease, were observed in between flow reversals. The static phases were accompanied with evaporator temperature rises and were attributed to mal-distribution of vapor/liquid volumes during its duration. Similar findings were found by Tong et al. [4] who utilized a video camera to qualitatively describe the internal fluid movement within a glass-tube OHP with an inner diameter of 1.8 mm and charged with methanol at a filling ratio of 60%. It was also found that the circulatory velocity increased with heating power.

Borgmeyer et al. [5] measured liquid slug displacements within a two-loop FP-OHP sealed with an acrylic cover using a high speed camera and software. The FP-OHP was tested with water and ethanol and it was found that the working fluid, heat input and operating orientation affected the internal amplitudes and speeds of liquid slug movement. Bulk circulation of the working fluid was observed to accompany local fluid oscillations and this motion was found to increase with heat input and be very sensitive to

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