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The transient response of wicked heat pipes with non-condensable gas

Sameh M.I. Saad, Chan Y. Ching*, Daniel Ewing

McMaster University, Department of Mechanical Engineering, Hamilton, ON L8S 4L7, Canada

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ABSTRACT

Experiments were performed to evaluate the effect of non-condensable gases and axial conduction on the transient performance of copper-water wicked heat pipes. An existing transient network model for wicked heat pipes was extended to incorporate the effects of axial conduction and non-condensable gas. The different components were modeled by a larger number of smaller elements in both axial and radial directions. The model predictions of the steady and transient response of the vapour and wall temperature of the heat pipes were in good agreement with the experimental results. The non-condensable gases and axial conduction did not significantly affect the transient response during the heat-up phase; however, it significantly slows down the cool-down phase.

1. Introduction

Heat pipes are being increasingly used in thermal management applications due to their low thermal resistance. For example, heat pipes have been used in the die casting and injection molding industry for controlled removal of heat during the solidification process, which is critical for product quality. Accurate predictions for the transient response of the heat pipe and the conjugate heat transfer in the surrounding medium is necessary to design thermal management systems in these applications. A number of models have been developed to predict the transient performance of ideal heat pipes including those that considered the two-dimensional heat transfer in the wick and wall and two-dimensional models for the vapor flow [1–4]. The predictions from the two-dimensional heat transfer model [3] were shown to be in reasonable agreement with measurements of the transient in a copper-water heat pipe [5].

The dynamics of the vapor flow can be important during the start-up or transients in high temperature applications, but the vapor flow has a much smaller time constant and thermal resistance than the wall and wick in lower temperature applications. The presence of non-condensable gases in the heat pipe core can have a significant impact on the performance of the heat pipe in both cases. The effect of non-condensable gases on the steady state performance of heat pipes has been considered assuming a sharp flat front interface between the gas and the vapor at a location based on the partial pressures of the vapor and gas [6]. The effect of diffusion between the working vapor and non-condensable gas and axial heat conduction through the walls was considered in later models [7–9] and it was found that the axial wall heat conduction had a much greater effect in predicting the position of the vapor-gas interface. Good agreement was found for the steady state results when axial conduction was considered [7].

The effect of non-condensable gases on the transient response of heat pipes has been considered in lumped transient models for the condenser section using a flat front model to predict the length of the region affected by the presence of the non-condensable gases [2,10,11]. The models either ignored wall conduction or approximated its effect using an extended fin-type model to estimate the effective length of the condenser region. The results were in good agreement with the experimental data for a high-temperature gas-loaded sodium heat pipe [12]. The movement of the vapor-gas front during the start-up performance of a high-temperature argon gas-loaded liquid metal heat pipe was observed to cause a significant local gradient in the axial temperature profile measured on the outside of the heat pipe [13,14]. It was suggested that the resulting axial conduction could be important during start-up and the effect of axial conduction throughout the heat pipe should be included in heat pipe transient models.

The objective of this investigation was to examine the effect of non-condensable gases and axial conduction on the transient performance of wicked heat pipes. Experiments were performed using a copper-water heat pipe with a woven copper wire screen mesh wick. To better understand the effect of non-condensable gases and axial conduction, the transient network model of [15] was expanded to include non-condensable gas in the core region and axial conduction throughout the heat pipe. The model is useful to

* Corresponding author. Tel.: +1 905 525 9140x24998; fax: +1 905 572 7944.
E-mail address: chingcy@mcmaster.ca (C.Y. Ching).

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