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Thermal performance and capillary limit of a ceramic wick applied to LHP and CPL

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ABSTRACT

The performance of a ceramic wick working as a capillary evaporator of a Loop Heat Pipe (LHP) and a Capillary Pumped Loop (CPL) is analyzed. The LHP and the CPL have a capillary evaporator with 10 mm of inner diameter and 25 mm of length. The LHP compensation chamber has the same diameter as the evaporator and a length of 50 mm. The ceramic wick was sintered from alumina and mullite powders, achieving 50% of porosity, 1–3 μm pore size distribution and permeability of 35×10^{-15} m^2, and then machined to properly fit the evaporators. The performance tests were carried out using deionized water as the working fluid for power inputs of up to 30 W. The thermal performance, capillary limit and area-specific thermal resistance of these systems were analyzed with the support of basic heat transfer and fluid flow lumped models. The lowest area-specific thermal resistance values of 31.7 °C/W/cm^2 for CPL and 25.0 °C/W/cm^2 for LHP were reached when dissipating 3.18 W/cm^2, while the highest values of 52.8 °C/W/cm^2 for CPL and 38.8 °C/W/cm^2 for LHP were reached while dissipating 0.53 W/cm^2 and 1.06 W/cm^2, respectively. The analysis shows that the systems operate well at their capillary limit and their performance is equivalent to similar devices operating with acetone and ammonia reported in the literature.

1. Introduction

In recent years the reliability and applicability of LHPs and CPLs has been studied in relation to the thermal control of electronic equipments. In this context, the study reported herein consists of an analysis of the thermal behavior of LHPs and CPLs taking into account changes in the working fluid, number of evaporators and condensers, inclination of the systems, materials for the systems and materials for the porous wicks [1–8].

The porous wick characteristics, such as the effective thermal conductivity, pore diameter, porosity and permeability, have a significant effect on the CPL and LHP performance. Nowadays, most LHPs and CPLs use polyethylene or metallic wicks in the evaporator. There are few CPLs [2,4–6] and LHPs [1,3,7,8] which use ceramic wicks.

This study represents an extension to the results reported in [7]. Experiments and modeling were carried out to quantify the thermal performance and applicability of a ceramic wick in the capillary evaporator of a LHP and a CPL. The ceramic wicks, as described in [7], are sintered from alumina and mullite compacted powders and then machined to properly fit the evaporators. The application of ceramic wicks in capillary evaporators represents a potential alternative to wicks made of metal and plastic. Once the fitting and sealing problems have been overcome, their advantages of excellent thermal stability, compatibility with metals, possibility of tailoring pore sizes and porosity and freedom in the choice of sizes and shapes become evident. The thermal performance, the capillary limit and the total thermal resistance of these systems are presented and analyzed using heat transfer and fluid flow resistance models. The performance tests were carried out for power inputs ranging from 5 to 15 W for the LHP and from 5 to 30 W for the CPL using water as the working fluid.

2. Experiment

A LHP and a CPL were manufactured and tested in order to evaluate their thermal performance and their applicability in the thermal control of microprocessors and electronic components in general. The surface temperatures of the main parts of the systems, *e.g.*, evaporator and condenser inlet and outlet, compensation chamber (in the case of LHP) and reservoir (in the case of CPL) were measured while the thermal load was varied. Both systems used water as the working fluid. The systems had a ceramic wick

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installed in the capillary evaporator. For the heating of the capillary evaporators, electrical resistors (cartridge heaters inside of a copper block for the LHPs and heaters in the format of a wire for the CPL) were used to simulate the heat generation in microprocessors and electronic components. The condenser of the LHP was cooled using water under forced convection and the condenser of the CPL was cooled using air (also under forced convection).

Fig. 1(a) shows the LHP in which the capillary evaporator has 10 mm of inner diameter and 25 mm of length, the compensation chamber has the same diameter as the evaporator and a length of 50 mm, the transport lines of the liquid (length of 260 mm) and vapor (length of 245 mm) have 2.8 mm of inner diameter and the condenser has 120 mm of length. Fig. 1(b) shows the CPL in which the capillary evaporator has 10 mm of inner diameter and 25 mm of length, transport lines of the liquid (length of 140 mm) and vapor (length of 205 mm) have 2.8 mm of inner diameter and the condenser has 385 mm of length.

The ceramic wick used in the LHP and CPL has 50% of porosity, 1–3 μm pore size distribution and permeability of around 35×10^{-15} m^2. Fig. 2(a) shows a view of the evaporator, the compensation chamber and the ceramic wick of the LHP. Four grooves with length of 10 mm were machined in the ceramic wick used in the LHP (on the upper side of the capillary evaporator only). In the course of the study, the machining technique was improved and it was possible to machine more vapor channels (12 grooves with length of 25 mm) in the ceramic wick used for the CPL, Fig. 2(b). In contrast to the wick for the LHP, whole the circumference of CPL capillary evaporator has grooves. A thermal cleaning at 800 °C for 60 min is applied to remove the oil contamination after the machining.

The temperature distribution along the LHP was measured using thermal resistors (PT_{100}). Fig. 3(a) depicts the locations of the temperature sensors: evaporator outlet ($T_{Evap,out}$), condenser inlet ($T_{Cond,in}$), condenser outlet ($T_{Cond,out}$), evaporator inlet ($T_{Evap,in}$) and the compensation chamber (T_{CC}). The temperature distribution along the CPL was measured using type-T thermocouples. Fig. 3(b) shows the locations of the temperature sensors: evaporator (T_{Evap}), evaporator outlet ($T_{Evap,out}$), vapor line ($T_{VaporLine}$), condenser inlet ($T_{Cond,in}$), condenser (T_{Cond}), condenser outlet ($T_{Cond,out}$), evaporator inlet ($T_{Evap,in}$), reservoir (T_{Res}) and reservoir outlet ($T_{Res,out}$).

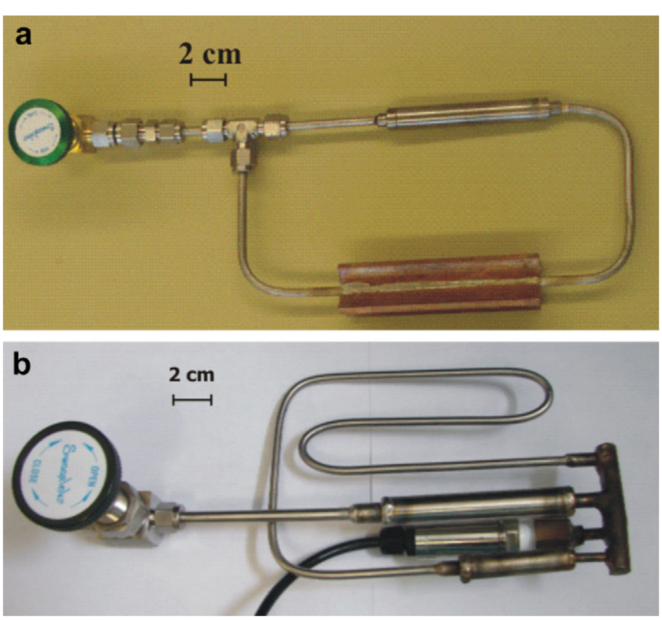

Fig. 1. (a) General view of the LHP and (b) CPL.

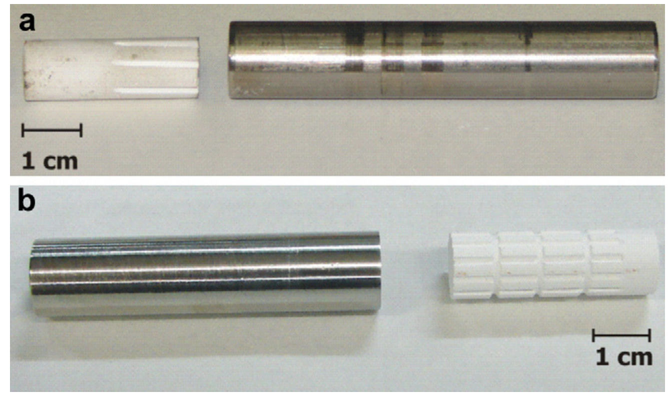

Fig. 2. (a) Ceramic wick with vapor channels (grooves) used in the LHP and (b) CPL.

The LHP and CPL were developed for the thermal control of electronic components. Thus, if the design of these devices was not satisfactory, high operation temperatures of the electronic components will effect their performance and reliability [9]. According to [10], the failures in these electronic components increase quasi-exponentially in function of their operation temperatures which should not exceed typical values between 85 and 100 °C. Therefore, here it was assumed the limit temperature of 100 °C for the operation temperatures of the LHP and CPL.

During the tests, the following procedure was adopted. The LHP and CPL were first adjusted to the horizontal position and the

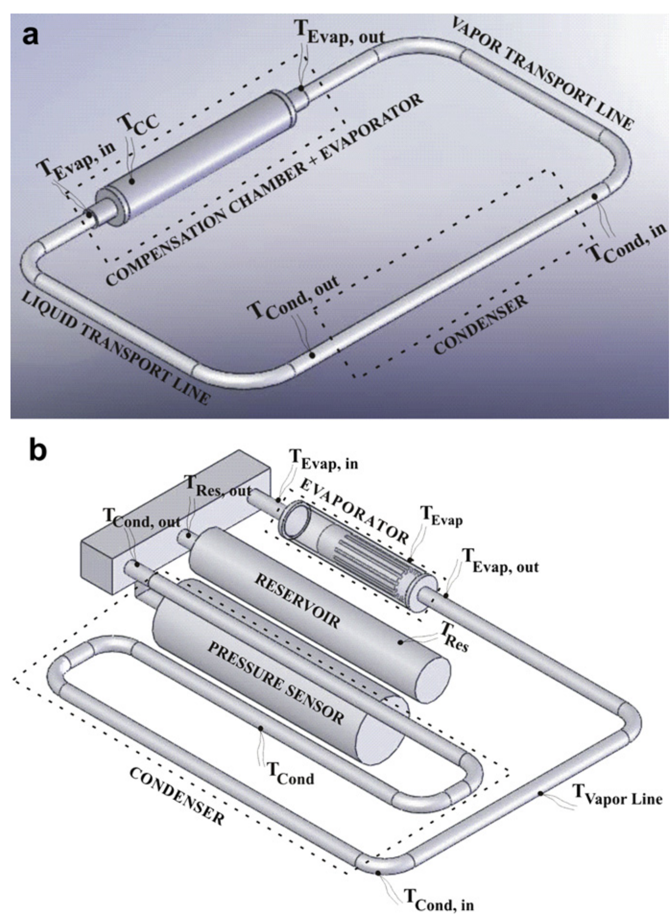

Fig. 3. (a) Positions of the thermal sensors along the LHP and (b) CPL.