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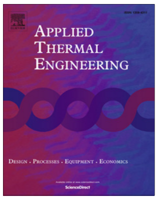

Research Paper

Important factors affecting the thermal resistance and thermal diffusivity of vapor chambers

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HIGHLIGHTS

- Comparison of thermal resistance in vapor chambers under various types of Experiment Setup.
- The lowest resistance was observed for VC under constant temperature conditions.
- Measurement of thermal diffusivity in vapor chamber using the Angstrom method.
- Thermal diffusivity of vapor chamber was 36 times higher than that of copper plate.

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ABSTRACT

This paper discusses a number of important parameters associated with the measurement of thermal resistance and thermal diffusivity in vapor chambers (VCs). Thermal resistance and thermal diffusivity are representative indicators of VC performance. In this paper, we measured thermal resistance using four distinct Experiment Setups. Our empirical results demonstrate that thermal resistance values depend largely on how the experiment is set up. We also examined two different condensation methods in the measurement of thermal resistance. Condensation condition 1 uses cooling water with an input temperature fixed at 20 °C and the flow rate fixed at 10 g/s. Condition 2 involved fixing the temperature of the top surface of the vapor chamber by adjusting the temperature of the cooling water according to the input power. In experiments, the lowest thermal resistance was 0.135 °C/W under condensation condition 1 and 0.023 °C/W under condensation condition 2.

We also developed a device for the measurement of thermal diffusivity based on the Angstrom method. We then measured (under experimental conditions) the thermal diffusivity of four pure metals for comparison with standard reference values. The thermal diffusivity values were measured as follows: VC ($44.04\ \mathrm{cm^2/s}$) and copper plate ($1.219\ \mathrm{cm^2/s}$).

1. Introduction

Vapor chambers (VCs) comprise a flat plate heat pipe capable of spreading heat very efficiently. They have been widely studied due to their potential applicability in cooling high-power electronic chips [1]. Fig. 1 presents a schematic diagram showing a VC, in which the bottom plate act as an evaporator and the top plate acts as a condenser. When heat is applied to the evaporator, liquid in the evaporator region absorbs heat and vaporizes. The vapor moves to the condenser region where it releases the heat. The condensed liquid then flows back to the evaporator zone through a wick structure, and the cycle is repeated. The key parameters in the performance of VCs are the structure of the wick, the selection of working fluid, and the structure of the vapor path [2].

Koito et al. [3] studied the effects of heat source size on the heat transfer characteristics of VCs. Their numerical results indicate that thermal resistance decreases in inverse proportion to the size of the heated area. They also identified thermal resistance in the evaporator section as a key factor of VCs. Boukhanouf et al. [4] investigated the performance of VCs using an infra-red (IR) thermal imaging camera. Their VC presented excellent heat spreading over a wide range of heat flux inputs. Wong et al. [5] proposed a novel VC in which the conventional wicked top condenser wall is replaced by a top plate with fine parallel grooves, while retaining the sintered wick on the bottom plate. Experiment results demonstrated that the thermal resistance of this novel VC is lower than that of conventional VCs. Wong et al. [6] investigated the performance of VCs using dummy heaters of 1.21, 4.41, and 9.61 $\mathrm{cm^2}$.

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Nomenclature

A	area [mm^2]
α	thermal diffusivity [cm^2/s]
h	coefficient of heat loss
K	thermal conductivity [W/m K]
L	distance between T_1 and T_2 [cm]
M	temperature amplitude at T_1 [°C]
N	temperature amplitude at T_2 [°C]
P_m	power amplitude [W]
Q	power [W]
R_{th}	thermal resistance [°C/W]
Δt	sine wave transmitted from the heating cycle of the delay time T_1 to T_2 [s]
T	temperature [°C]
τ	aspect ratio, thickness divided by width

Subscripts

eva	evaporator
H	heater
in	input
max	maximum heat transfer

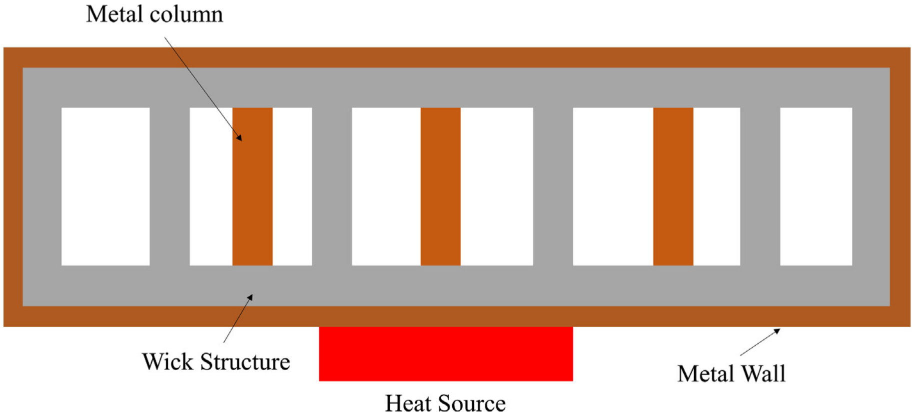

Fig. 1. Schematic of vapor chamber.

The minimum thermal resistance in the vapor chamber decreased with an increase in heated area. These effects were explained by the thickness distribution of the evaporating film with respect to the heated area. Tsai et al. [7] investigated the thermal characteristics of VCs and the effect of gravity on their performance. They found that thermal resistance decreased with an increase in the input heat load. They also identified thermal spreading resistance as the dominant factor determining the overall thermal resistance of the vapor chamber. Li et al. [8] characterized the thermal performance of VCs using various parameters, including wick structure, filling rate, size of copper particles, and heating area. They reported that the filling rate is primarily responsible for the response time and uniformity of temperature within the device, whereas the cooper particle affected the thermal resistance. Lu et al. [9] conducted a numerical study on the thermal and hydraulic performance of VCs using a cen-column in three dimensions. Their numerical results indicated that identifying the optimal column diameter can significantly improve the circulation of liquid without decreasing thermal uniformity. The mean radius of the sintered powder particles must be decreased to accommodate a decrease in column diameter. They also reported that a compound device combining a solid pillar and sintered ring in a coaxial arrangement could be used to improve VC performance. Chang et al. [10] examined the thermal performance of a novel thin loop-type vapor chamber.

The Angstrom method is a means by which to measure steady-state temperature oscillations to determine thermal diffusivity α [11]. The Angstrom method is based on one-dimensional periodic heat transfer in which the boundary condition is a sinusoidal heating flux. When a steady-state is reached, thermal diffusivity can be determined according to the temperature distribution at two separate two points [12]. Bodzenta et al. [13] studied the thermal diffusivity of various materials used in dental fillings. They achieved satisfactory accuracy of $0.295 \times 10^{-6}\ \mathrm{m^2\ s^{-1}}$ for Achatit Bichromatic, $0.321 \times 10^{-6}\ \mathrm{m^2\ s^{-1}}$ for charisma, and $1.70 \times 10^{-6}\ \mathrm{m^2\ s^{-1}}$ for Dentimet. Using this approach in measuring samples with a cylindrical shape, Santos et al. [14] obtained reproducible results comparable to those in the literature. Zhang et al. [15] studied the thermo-physical properties of one-dimensional super-aligned carbon nanotubes (SACNTs). They demonstrated that the density of SACNT buckypapers determines the thermal diffusivity.

Thermal resistance is the parameter most commonly used to indicate the performance of VC; however, the resulting values are largely determined by the specifics of the experiment, including condensation condition, contact resistance, and the setup. The main purpose of this paper was to develop experimental methods with which to facilitate the measurement of thermal resistance and thermal diffusivity in VCs. We used these results to establish standard test principles for use as a reference by the TTMA (Taiwan Thermal Management Association). The formulation of test principles was necessitated by the fact that the manufacturers of vapor chambers tend to rely on proprietary test methods, which tends to cause considerable confusion among the venders of computer systems seeking to evaluate VCs. The fact is that the results are largely determined by the test methods employed.

In this paper, we measured the thermal resistance under four Experiment Setups. We also adopted two different approaches to condensation in measuring thermal resistance. Condensation condition 1 involved the use of cooling water with input temperature fixed at 20 °C under a flow rate of 10 g/s. Condition 2 involved fixing the temperature of the top surface of the vapor chamber by adjusting the temperature of the inlet cooling water according to

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