Applied Thermal Engineering 140 (2018) 131–138

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

The experimental investigation of a vapor chamber with compound columns under the influence of gravity

Wangyu Liu*, Jingren Gou, Yuanqiang Luo, Min Zhang

School of Mechanical and Automotive Engineering, South China University of Technology, Wushan Road, Tianhe District, Guangzhou 510641, People's Republic of China

HIGHLIGHTS

- A vapor chamber with compound columns was designed, fabricated and tested.
- Copper foam was utilized in this VC and the flow mechanism was explained.
- The thermal behavior of the VC was carefully analyzed at the vertical position.
- The designed column was proved to reduce the influence of the gravity on the VC.

ARTICLE INFO

Keywords:
Vapor chamber
Compound columns
Gravity
Parametric investigation
Thermal performance

ABSTRACT

In this work, a new vapor chamber (VC) was fabricated and tested, on which a novel compound columns was proposed by considering the mechanical property and the thermal performance comprehensively. The columns consisted of the solid copper bars and the porous functional structures sintered on the cylinder surface of the pillars. Copper foam was selected to manufacture the wick structures and the cladding layers due to its distinct porous structures. To verify the superiority of the compound columns, a testing system was used to evaluate the thermal behaviors of the VCs under different inclination tilts. In this parametric investigation, the filling ratios included 70% and 100%, the sintering layer porosities were configured as 0%, 50% and 95%, and the heat loads varied from 6 W to 96 W. The experimental results indicated that the cladding layers of the columns enhanced the capillary limit and contributed to recycling the working fluid in the anti-gravity position, which finally broaden the adaptability of the VC.

1. Introduction

In recent years, the excessive heat flux has been an obstacle to the development of the electronic industry, such as LED and PC hardware [1,2], because of its demand for the ever-increasing power and the miniaturization design. To improve the heat dissipation capability, many devices were studied by researchers. Heat pipe and vapor chamber (VC) were considered as sophisticated solutions to the problem. However, compared with the heat pipe, VC performs better by conducting heat in all directions from the hot spot without efficiency loss [3].

VC has a high efficiency of heat dissipation due to its working mechanism of the two phase change process. In general, a VC consists of columns, a vacuum chamber and wick structures which are sintered on the evaporation and condensation plates. Based on the exquisite design, a VC can keep steady operations in a long time. In a vacuum atmosphere, the boiling point of liquid is much lower than the outer environment, as a result the liquid at evaporation wick can absorb heat and easily evaporate. When the heated gas reaches the cooled condensation zone, it releases latent heat and changes to liquid state. Correspondingly the working fluid flows back to the evaporation zone via the paths provided by columns and wick structures, after that the cycle is repeated. In the complete circulation, the capillary pressure generated by porous media plays a significant role in recycling the liquid. Therefore the porous media have been wildly used in VC applications. Li et al. [4] conducted experiments of copper-powder-sintered VCs (CPVCs) and copper-foam-sintered VCS (CFVCs) by setting various parameters. Hwang and Fleming [5] designed and tested a low thermal/hydraulic resistance, multi-artery heat-pipe spreader VC. In addition to wick structures, porous media were also utilized to optimize the supporting columns. Experiments were frequently implemented to verify their ideas under various conditions, such as heat loads, inclination tilts and filling ratios [6–8]. Wong et al. [9] presented a novel columns fabricated as triangular prism using sintering copper powder

---

* Corresponding author.
E-mail address: mewyliu@scut.edu.cn (W. Liu).

https://doi.org/10.1016/j.applthermaleng.2018.05.010
Received 20 December 2017; Received in revised form 20 March 2018; Accepted 4 May 2018
Available online 05 May 2018
1359-4311/ © 2018 Elsevier Ltd. All rights reserved.

structure. Two kinds of working fluid were tested in the comparison experiments. The results showed that VC using water as working fluid had the lowest thermal resistance due to its larger latent heat. Naphon and Wiriyasart [10] carried out parametric studies including different heat fluxes, number and sizes of sintering wick columns, and flow rate of coolants. It indicated that the number of wick column had an important influence on the velocity and pressure phenomena of working fluid. Wiriyasart and Naphon [11] presented a VC with sintering wick columns embedded plate fin. They designed experiments with different working parameters as well as developing a numerical model to predict the velocity and pressure distributions. The result showed that the capillary pressure was important for the working fluid circulation, evaporation rate and flow directions of the liquid and vapor phases. From the aforementioned results, wick columns partially determined the thermal performance of VCs. However, wick columns manufactured by pure porous materials still have defects. Compared with solid copper pillars, the wick columns have lower strength and higher thermal resistance because of the dense pores. For this reason, some researchers attempted to combine the advantages of wick columns and solid columns. Lu et al. [12] came up with a numerical model to analyze a sintered central column. In his design, the copper powder was sintered on the surface of the solid copper columns. As a result the column kept fine mechanical strength as well as porous structures which were necessary to recycle the liquid. In Tang's paper [13], he used experimental methods to prove the superiority of the columns design advised by Lu [12].

In the existing literatures, many researchers have taken tilt angles into consideration [6–8]. It was found that gravity hindered the fluid circulation when the inclination of VCs changed from 0° to 90°, but solutions were not given in their papers. Although Lu et al. [12] and Tang et al. [13] presented an improved structure, they only focused on the impacts caused by power and area of the heat source. Here, to combine the merit of wick and solid columns and eliminate the negative effect caused by the gravity, a new type of porous material, copper foam, was sintered on the cylindrical surface of the solid copper bars as porous functional structures. Besides, to enhance the transport capacity of the copper foam, fractal micro channels were carved on its surface. Furthermore, VCs with the novel design were fabricated and tested. In the series of experiments, comparisons of the VC samples with the cladding layer porosities of 0%, 50%, 100%, the heat loads varying from 0 W to 96 W and the filling ratios including 70% and 100% were carried out in different tilts. At last the phenomena influenced by the above variables were carefully analyzed.

2. Experimental setup and procedure method

2.1. Schematic of VCs

As mentioned before, a VC was divided into columns, a vacuum chamber and wick structures which were sintered on the internal surface of a copper enclosure. The overall dimension of the VCs was designed as 66 mm × 66 mm × 5 mm. The metal shell included 1 mm thick top and bottom walls and 3 mm thick side walls which functioned as a part of the supporting structure. In this investigation, copper foam with 95% porosity served as base materials for the wick structures. To avoid plastic deformation resulted by the pressure difference, the solid copper columns with 3 mm diameters and 3 mm height were configured as a 5 × 5 square array. As the focused point in this paper, the solid columns were sintered with 0.8 mm thick copper foam layer, by which the capillary pressure was generated to pump the liquid from condensation zone to evaporation zone. Compared with the conventional porous materials, such as sintered copper powder and sintered copper mesh net, the advantages of the copper foam are as follows: (1) Copper foam has a higher porosity, some even reach 95%. (2) Copper foam has a special porous structure with multiple-scale pores which guarantees an adequate driving force. As Ji et al. [14] pointed out that in a copper foam sample with 95% porosity, the equivalent diameters of the pores varied from 0.09 mm to 0.772 mm. (3) Copper foam has a more uniform thickness. (4) The micro-channel structure significantly decreases the shear stress at the vapor-liquid interface during the counter-current flow of the two phases [14]. For those reasons, copper foam was selected as the material for the wick structures and the cladding layers of the columns. To further understand the working mechanism of the designed VCs, porosities of the cladding layers, filling ratios and heat loads were all taken into account as experimental parameters. The complete details of the tested VCs are listed in Table 1.

Table 1
Detail parameters of different samples.

Sample	Porosity of the wick structure ε (%)	Porosity of the cladding layer ε (%)	Filling ratio ξ (%)
S1	95	95	70
S2	95	95	100
S3	95	50	100
S4	95	0	100

The thermal resistance and temperature uniformity were commonly defined to evaluate the thermal performance of VCs. In this paper, temperature uniformity was considered as the difference between maximum and minimum temperature on the external surface of the condensation end. The formula was established as follows:

$$\Delta T = T_{\max} - T_{\min} \tag{1}$$

In Tsai's research, the vapor chamber thermal resistance was divided into two components, one-dimensional resistance R_{1D} and spreading resistance R_S, which vanish as the source area approaches the vapor chamber size area. They were derived by

$$R_{1D} = \frac{\overline{T_e} - \overline{T_c}}{q}, \quad R_S = \frac{\overline{T_h} - \overline{T_e}}{q} \tag{2}$$

The total thermal resistance of VCs can be expressed by

$$R_{vc} = R_{1D} + R_S = \frac{\overline{T_h} - \overline{T_c}}{q} \tag{3}$$

where $\overline{T_h}$ is the average temperature of heat source, $\overline{T_e}$ is the average temperature of evaporation outer surface, $\overline{T_c}$ is the average temperature of condensation outer surface and q is the heat input power.

2.2. Manufacture procedure

First of all, milling operations were used to manufacture two 1 mm thick copper plates, one of which was fabricated with solid columns on its surface. Then the 0.8 mm thick copper foam was cut into 60 mm × 60 mm and 3 mm × 9.5 mm films which served as wick structures and cladding layers respectively. Micro channels were carved on the 3 mm × 9.5 mm films by tungsten steel tools. The detailed structure observed by microscope was shown in Fig. 1. The copper foam sheets and the copper plates were compacted by exclusive graphite mold and the samples were placed at 950 °C in reducing atmosphere for 3 h. As the thermal expansion coefficient of copper was larger than graphite, the copper foam and copper plates were constrained tightly by the heavy mold at a high temperature. The two copper plates and the feeding tube were sealed as a metal enclosure at 950 °C in reducing atmosphere for 30 min. In this operation, solder paste was firstly applied on the edges of one copper plate as well as the joint with the feeding tube, then the copper plate was covered by the other one. Later, they were clamped by two graphite plates and were sent to an oven. After the sintering process, deionized water was injected to the enclosure through the feeding tube. The filling ratio can be defined as the following formula:

Download English Version:

https://daneshyari.com/en/article/7045009

Download Persian Version:

https://daneshyari.com/article/7045009

Daneshyari.com