Energy Conversion and Management 166 (2018) 512–521

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Various orientations research on thermal performance of novel multi-branch heat pipes with different sintered wicks

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ARTICLE INFO

Keywords:
Heat pipe
Orientations of gravity
Particle size
Multi-source
Heat transfer

ABSTRACT

The thermal performance in various orientations of gravity was investigated for operating multi-branch heat pipes (MBHPs) with different sintered wicks in the case of cooling a heat source with dual condenser. The effect of sintered particle size in different orientations on heat transfer performance were investigated systematically. The particle size effect was examined with three copper powders of particle size of 50–75 μm, 75–100 μm and 100–125 μm in four orientations of gravity-assisted orientation, anti-gravity orientation, horizontal orientation, and compound orientation of gravity, respectively. All MBHPs were filled by deionized water to the filling ratio of 100%. Experiment results indicate that all MBHPs can operate with similar performance in all the tested orientations before dry-out occurring. Further, the MBHP with 75–100 μm copper powder performs best in all the tested orientations, considering both the thermal resistance and the heat transport capability. In addition, it can start up successfully within 10 min without temperature overshoot and oscillation. That is, a MBHP can perform well in all the tested orientations and the copper powder of 75–100 μm is a good candidate for better thermal performance.

1. Introduction

In recent years, heat pipes have been studied extensively as a kind of passive heat transfer device with many excellent characteristics including high thermal conductivity, fast response and long lifetime [1–3]. And heat pipes are widely used in the thermal management of electronic devices, including civilian electronics, spacecraft components, satellites and so on, to ensure their stable operation [4–6]. With the development of above-mentioned fields, high performance and integration have become the main trends of electronic devices, which means that multi-heat or extreme heat sources are common configurations. For example, a computer can have multiple CPUs and a satellite can contain multiple heat dissipating components such as high power amplifier, frequency converter and power supply [7,8]. Therefore, it is a great challenge for conventional heat pipes to dissipate heat effectively from such high-integration electronic devices.

To compensate the drawback of conventional heat pipes with only one evaporator and one condenser, multi-source heat pipes (MSHPs) have been proposed to solve the cooling problem of these multi-heat source or high-power systems. Here, a MSHP is defined as a heat pipe containing more than one evaporator section or one condenser section. Numerous experimental and theoretical studies have been conducted on the thermal performance of these multi-source heat pipes. Bienert et al. [9] fabricated a breadboard loop heat pipe with two evaporators, which can start up reliably and also operate successfully with both uniform and non-uniform evaporator heat load. Okutani et al. [10] proposed a multiple-evaporator and multiple-condenser loop heat pipe with polytetrafluoroethylene porous media wick. They studied the behavior of the MLHP with heat loads to both evaporators and to only one of the evaporators, respectively. And it can stably operate up to 40 W/40 W and 0 W/50 W. Li et al. [11] developed a copper–water loop heat pipe with dual parallel condenser to cooling high-power integrated LED chips. The tested result showed that the junction temperature of the LEDs can be controlled below 85 °C and the thermal resistance is near to 0.4 °C/W at the heating load of 300 W. And they also found that a compact loop heat pipe with parallel condensers has better thermal performance than that with a single condenser [12]. Torresin et al. [13] proposed a novel pulsating heat pipe cooler with a double condenser area and chose R245fa as working fluid. The focus of their investigations was given to the effect of fluid filling ratio and orientation on thermal performance. And the experimental research result showed that the heat pipe is orientation-free and the maximal thermal resistance is 29 °C/kW at 60% filling ratio. However, the application of these loop/pulsating heat pipes will be confined in consideration of their volume and fabrication.

Considering the advantages of simple structure and convenient

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https://doi.org/10.1016/j.enconman.2018.04.066
Received 7 March 2018; Received in revised form 14 April 2018; Accepted 17 April 2018
Available online 03 May 2018

manufacture, some studies also concentrate on the simple cylindrical heat pipe for exploring its feasibility at multi-source heat dissipation. Mashaei et al. [14–16] reported a cylindrical heat pipe with two consecutive evaporation sections for satellite equipment cooling. They studied the effect of nanofluid on thermal performance and found that smaller nanoparticle size and higher concentration level could increase the heat transfer coefficient remarkably. Tang et al. [17] studied on the effect of inclination angles and cooling locations on thermal performance of a cylindrical heat pipe in the case of double-ended heating and middle-cooling. And the results revealed that the temperature of the evaporators can be controlled by placing the cooling source near to the upper evaporator when the inclination angle is a little large. However, for a cylindrical heat pipe, it is difficult to apply in the situation of complex spatial distribution of heat sources due to its single structure. Hence, a novel multi-branch heat pipe (MBHP) with sintered wick has been proposed by our group, which is an improved configuration of the cylindrical heat pipe [18]. And the previous experimental results indicated that the optimum filling ratios for water is between 75% and 100% and the optimum thermal performance with thermal resistance of 0.04 °C/W and heat flux of 328.3 W/cm^2 can be reached at a total heat load of 160 W. The multi-branch heat pipe has a good application prospects in cooling the multi-source system due to its flexibility and thermal performance.

On the other hand, gravity is always an important factor affecting the thermal performance of heat pipes. As long as a heat pipe is proposed, the performance under different orientations of gravity is always mainly concerned by researchers [13,17,19–22], due to the complex application conditions in a real world. Tharayil et al. [20] compared the heat transfer of cylindrical and flattened heat pipes at various inclinations, and anti-gravity test are repeated to valid the reliability of these heat pipes. Khalili et al. [21] fabricated a novel sintered wick heat pipe and compared its thermal resistance with the conventional type one under various orientations, recommending that the new type one is more suitable for the condition where the gravity is negligible. For ultra-thin loop heat pipe, two samples with different channel configuration were studied under multi-orientations experimentally and numerically by Hong et al. [22]. They found that the sample with parallelogram evaporator configuration can start up faster and showed superior capability at all tested angles. Hence, for MBHP, the effect of gravity on the thermal performance is also essential and still unknown to us.

Aiming to make sure that the MBHP can be adapted to the complex working conditions, it is necessary to examine the thermal performance under multiple orientation conditions of gravity. Furthermore, the particle size of the sintered wick is also an important impact factor in the thermal performance of a sintered-wick heat pipe, since it can change the influence of gravity with the action of capillary force and permeability [23,24].

In this paper, the thermal performance of multi-branch heat pipes under different operating orientations are studied systematically with three different particle size sintered wicks. The dissimilarities between their heat transfer characteristics including the operating temperatures, the thermal resistances and the start-up features are all explored. Meanwhile, the advantages of the structure of MBHP are further confirmed, and the results can also be used to guide the application of MBHP for solving the heat dissipation problem of multi-source systems.

2. Experiments

2.1. The construction of MBHP

The MBHP is primarily composed of three cylindrical copper shells, a T-shaped copper joint and a consecutive sintered wick (see Fig. 1). The length and outer diameter of each copper shell is 100 mm and 8 mm, the inner diameter of the copper joint is also 8 mm and the diameter of the vapour lines is 5.5 mm. The sintered wick is attached to

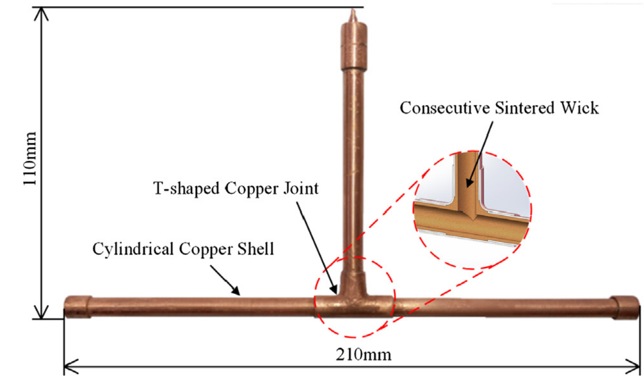

Fig. 1. Prototype of a multi-branch heat pipe.

the inner wall of the MBHP, which is 0.85 mm thick and made of copper powder with a certain particle size range. The consecutive sintered wick provides capillary force to accomplish the working circulation inside the MBHP. Hence, in order to ensure the continuity of the sintered wick inside the MBHP, the copper cylindrical shells and the copper joint are welded first, and then the copper powder is filled and sintered with the help of graphite core rod.

Deionized water is selected as working fluid due to its good compatibility with copper and the highest merit number among all the low-operation-temperature working fluids [11,25]. According to results of preliminary experiments, the filling ratio of deionized water selected is 100%. Here, the filling ratio is defined as the ratio of the volume of fluid filled to the whole pore volume of the sintered copper powder wick. Table 1 summarizes the main geometrical parameters of the proposed MBHP.

In this study, the whole MBHP can be divided into four parts: an evaporator, two condensers and adiabatic section, and the two condensers are in the two opposite branches. When the evaporator is heated externally, the inner working fluid is evaporated into vapour. Then the pressure difference between the evaporator and the condensers occurs, which forced the high-temperature vapour to flow toward the condensers through the vapour line and release the latent heat of vaporization. Afterwards, due to capillary force of wick, the condensate liquid returns back to the evaporator through the liquid line and the working cycle repeats. The length of the evaporator and the condensers were 50 mm and 70 mm, respectively, and the rest of it was allocated to the adiabatic section.

2.2. Experimental setup

The detail of the experimental setup used for testing the thermal performance of the MBHP is shown in Fig. 2. Two commercial cylindrical cartridge heaters were soldered in two copper blocks with a semicircular slot, respectively, which is used as heating source (dimensions of 50 × 35 × 24 mm^3) and can also provide a heating power from 0 to 200 W by a variac. The two copper blocks were screwed to the evaporator of the MBHP by clamping the heat pipe firmly. To minimize the environmental heat losses, the heating copper block and adiabatic

Table 1
Geometrical parameters of the proposed MBHP.

Parameters	Value/material
Pipe material	Copper
Working fluid	Deionized water
Length of branch	105 mm
Pipe outer diameter	8 mm
Pipe wall thickness	0.4 mm
Sintered wick material	Copper powder
Sintered wick thickness	0.85 mm