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Effect of working fluid on heat transfer performance of the anti-gravity loop-shaped heat pipe

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ABSTRACT

This paper investigates the effect of working fluid on the thermal performance of the Anti-Gravity Loop-Shaped Heat Pipe (AGLSHP). In the experiments, the AGLSHP is designed and tested for the ground-surface condition, and deionized water is chosen as the working fluid. Two factors are selected in this study: (1) three different filling ratios (filling coefficient ε ranges from 80% to 120%); (2) two different wick structures, including single-powder (SP) and continuous step-graded (CSG) sintered wicks. The results indicate that the effect of the filling ratios of the working fluid is remarkable on the heat transfer performance. Specifically, the low filling ratio sample shows much better start-up characteristic, while the high filling ratio sample is quite outstanding at the high heat load. Simultaneously, the thermal resistance also increases significantly with the rise of working fluid mass. In addition, the CSG sintered wick structure can not only effectively promote the properties of the AGLSHP, but also facilitate the circulation of working fluid. Moreover, the SP structure is invalid at the heat load of 50 W, but the limiting heat load of the CSG structure can reach 70 W with the peak temperature under 110 °C at the outlet of the evaporator. In this research, it is also found that with identical working liquid mass, these two kinds of sintered wicks both show obvious partial-dry-out phenomenon at high temperature.

1. Introduction

In recent years, novel cooling devices have been developed to overcome the heat dissipation problem of the electronic components, such as heat pipes, flat plate heat pipes and pulsating heat pipes [1–3]. Loop heat pipe (LHP), as one of the most important phase change heat transfer devices, was firstly invented in 1972 by Maydanik and applied in the area of the aerospace technology [4,5]. However, the challenge lied in the fact that traditional loop heat pipes could not subject to the influence of the gravity on the Earth's Surface, when the heat source was over the cold source. In order to address this problem, the Anti-gravity Loop-shaped Heat Pipe was presented by Tang et al. [6]. They found that with the help of the Continuous Graded Pore-Size Wick, Anti-Gravity Loop-Shaped Heat Pipe (AGLSHP) provided adequate capillary to deliver the working fluid from the condenser to the evaporator, so that it could operate in the terrestrial application.

In general, the working fluid is of vital meaning to the thermal performance of the heat pipes. Some previous works have demonstrated that the heat pipes are efficient in high heat flux microelectronic chips and in low cost as well, for the reason that phase changing of working fluid is essential to address the limitations above. Wu et al. [7]conducted an experimental investigation to study the thermal performance of the oscillating heat pipes charged with SiO_2/water and Al_2O_3/water, nano fluids, respectively. Their results demonstrated that different effects were induced because of the different additions of the nanoparticles into the water, and the deposition behaviours were the main reason for the thermal performance. Zhang et al. [8] investigated in the pulsating heat pipe with three different working fluids-FC-72, ethanol, and deionized water. They found that the minimum heating power was considerably dependent on the working fluid types, and was smaller when it was filled with FC-72. They also proposed that the optimal filling ratio was approximately 70%. Furthermore, instrumental investigations of the processes of condensation and redistribution of a working fluid in a loop heat pipe were carried out by Bartuli et al. [9]. They measured the temperature field in the condenser, and analyzed the heat-transfer coefficients and the

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thermal resistances. Wilson et al. [10] presented a thermal experimental investigation with four oscillating heat pipes (OHPs) and used acetone and water as working liquid. It was shown that the acetone OHP at low power performed better than the water OHP, while at high power the water OHP exceeded the acetone OHP. They concluded that improving the flow of the working fluid in connecting turn would increase the closed loop OHP's performance.

The working fluid also influenced the thermal performance of the heat pipes based on different wick structures. The circulation of the working fluid, including the evaporating, condensing, transferring, is connected with the wick's capillary of the wick. Wu et al. [11] developed a double-layer wick structure to improve the transfer of the working fluid of a biporous wick under higher heat flux, which provided a high capillary force and increased the strength of the outer layer. The results illustrated that the double-layer wick had a 67% higher maximum heat load and an almost half lower total thermal resistance. An integrated trapezium-grooved-wick micro heat pipe was put forward by Li et al. [12] to investigate in the capillary force and the heat transfer performance. They analyzed that the capillary limit was evidently superior to the compound wick, in comparison with that of a micro heat pipe with a simplex grooved wick or a simplex sintered wick. Chen et al. [13] used two types of aluminium vapour chambers to study the phase change phenomena. The manufacturing samples were micro heat pipes with a simplex grooved wick or a simplex sintered wick. It was shown that the thermal resistance of sintered powders vapour chamber was more stable than the other one. A mathematical model of evaporative heat transfer in loop heat pipe was presented by Lin et al. [14]. The comparison experiments were also conducted with sintered nickel wicks of different pore size distributions. The predictions indicated that heat transfer characteristics and performance for the bidisperse wick were obviously higher than monoporous wick.

Although the above literature survey concentrated on the influence of working fluid and wick on heat pipes, the research about the relation between them seems to be limited. In this paper, effect of working fluid, especially the different filling ratios, is investigated based on the performance of the AGLSHP in detail. Moreover, the wick structure factors are analyzed and evaluated by means of the comparisons of the thermal resistance as well. The experimental data can be used to design and manufacture the AGLSHP in industrialized production stage. Furthermore, the results can be used to guide the study of the LHP in cooling modules.

2. Experimental

2.1. Fabrication of samples

In this study, two sets of AGLSHPs were fabricated by bending copper tubes, with an overall height of 300 mm and a width of 100 mm, as shown in Fig. 1. The copper tube used in this experiment had an outside diameter of 7.94 mm and an inside diameter of 7.53 mm, and the bending radius was 24 mm, respectively. Subsequently, the copper powders were filled into the copper tubes by means of loose-powder sintering technology [15]. In order to keep the vapour flowing along the vapour line, the copper powder in the evaporator was sintered with a core rod to form the cavity. Notice that the diameter of the cavity was 5.5 mm and the depth was 66 mm. The copper powders, produced by water atomization with irregular morphology, were supplied by Teachn Industrial Technology Co., Hunan, China, and the purity was 99.95% approximately. One thing to note here was that the sintering process was controlled in the furnace with the temperature of 900 °C for 60 min. During the process, nitrogen and hydrogen were used as the protective atmosphere to prevent oxidation. Thus, the AGLSHP sample was formed.

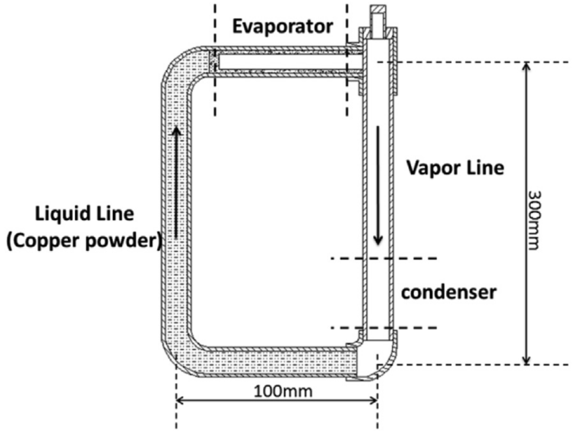

Fig. 1. Sectional view of the AGLSHP.

Evaporation, adiabatic, and condensation sections of the AGLSHP were designed and manufactured, respectively. In the evaporation section, the heating block was set close to the outer wall surface of the copper tube, and fixed by the socket head cap screw to keep it fastening. Meanwhile, the heat sink was chosen as the cooling equipment, and the fan was applied to detach heat. The materials of the evaporator and the heat sink were copper and aluminium. Moreover, in order to avoid the heat loss, it was wrapped up by heat preservation cotton entirely.

The AGLSHP was filled with working fluid via the technology of vacuuming and filling working fluid [16]. The main filling process consisted of two steps, vacuuming and filling working fluid. Firstly, the non-condensable gas was removed from the AGLSHP via the vacuum equipment, and the pressure inside the samples was 0.08 Pa. After that the working fluid was filled into the AGLSHP. Because of the special structure of the samples, there was a necessary to optimize the heat transfer performance by managing the filling ratio. The working liquid was shown in Eq. (1) below:

$$V = V_1 * \eta_1 + V_2 * \eta_2 + V_3 * \varepsilon \tag{1}$$

where V_1 and V_2 are the copper powder volume of the evaporator and the liquid line, and V_3 is the volume of the vapour line under the inlet of the condenser, as shown in Fig. 2. η_1 and η_2 represent the porosity of the wick in the evaporator and liquid line, and ε is the filling coefficient as shown in Fig. 3. The basic parameters of the AGLSHP tested in this study are listed in Table 1.

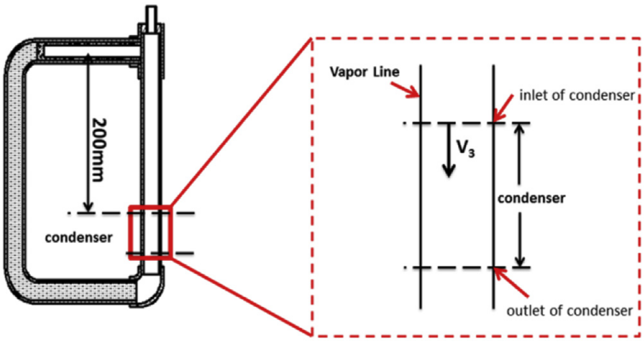

Fig. 2. Schematic diagram of the condenser.