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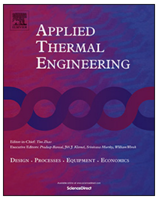

LHP heat transfer performance: A comparison study about sintered copper powder wick and copper mesh wick

Yiwei Wang, Jiwen Cen, Fangming Jiang *, Wenjiong Cao, Jian Guo

Laboratory of Advanced Energy Systems, CAS Key Laboratory of Renewable Energy, Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences (CAS), Guangzhou 510640, China

HIGHLIGHTS

- We experimentally study heat transfer performance of LHPs with different wicks.
- The sintered wick LHP performs a little better than the mesh wick LHP.
- The sintered wick LHP can start up at very low heat load.
- The main reason may be the sintered wick is of smaller pore size than the mesh wick.

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ABSTRACT

Heat transfer performance of loop heat pipe (LHP) is tightly related with the wick positioned between its evaporator and compensation chamber. Experiments were carried out to investigate the effects of wick on LHP heat transfer performance. Two wicks, a sintered copper powder wick and a copper mesh wick, were considered for comparison. The former has larger porosity; its pore size spans within a wide range, but smaller than that of the latter. The measured temperature data indicate that the sintered wick LHP starts up faster and operates more stably. The overall thermal resistance of the sintered wick LHP is also slightly lower than that of the mesh wick LHP. Moreover, the sintered wick LHP is found to be able to start up with heat load as low as 5 Watts.

1. Introduction

Loop heat pipe (LHP), relying on phase change (evaporation and condensation) of fluid to realize effective and fast heat transfer, was first created and successfully tested by two Russian scientists, Gerasiomov and Maydanik, in 1972 [1]. Due to its excellent long distance heat transfer ability, ease and flexibility of installing, LHP has been widely used in energy generation, conversion, and utilization-relevant fields, including aerospace [2,3], electronics cooling [4,5], and solar heating [6].

LHP consists of an evaporator, a condenser, a compensation chamber, and some vapor and liquid lines. Inside the evaporator, a wick, which is a very important part of LHP, is set to separate the compensation chamber from the evaporator. The wick is essentially a porous medium of capillary pore structure. The pore configuration (including size and shape of pores, and porosity) determines its macroscopic properties or performance, such as the permeability, effective thermal conductivity, and the maximum capillary force. A good wick requires having sufficiently large capillary force to prevent vapor from penetrating the wick and entering into the liquid line, high permeability to lower the flow resistance of liquid flow, and low thermal conductivity to reduce the through-plane heat leakage [7–9]. A single-structured wick may not meet all these requirements [10,11]. Developing high-performance wick is a hot research topic in the arena of LHP.

In recent years, numerous works [7–20] on heat transfer performance of LHPs with various wicks have been published. The most popular class of LHP wicks includes screen mesh wick and sintered metal powder wick. Ren et al. [8] developed a mathematical model for heat transfer in LHP wick to study the effects of porous structure parameters. Singh et al. [9] studied the effects of wick characteristics on LHP thermal performance and found from experiments that smaller pore size, larger porosity, and higher permeability in the sintered metal wick gave better LHP heat transfer performance. Espinosa et al. [10] measured the physical properties (porosity, permeability, maximum capillary pressure and thermal conductivity) of sintered metal wicks. Celata et al. [12] investigated the thermal characteristics of a flat disk LHP with a stainless steel mesh wick. Wang et al. [13] studied the startup and steady-state operation performance of a miniature LHP with a

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* Corresponding author. Tel.: +86 20 87057656; fax: +86 20 87057656.
E-mail address: fm_jiang2000@yahoo.com (F. Jiang).

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sintered copper wick; the LHP could start up under a 6 W heat load. Choi et al. [14] reported a miniature LHP using a sintered metal wick, which could transfer heat of 27.8 W/cm^2 flux to a place with a distance of 500 mm away and maintained the evaporator temperature below 70 °C.

Plastic and ceramic wicks can be viewed as a relatively new type of LHP wicks. Nagano et al. [15] and Nishikawara and Nagano [16] used PTFE as LHP wick. Owing to the low thermal conductivity of PTFE, the wick could reduce the heat leakage from the evaporator to the compensation chamber. Santos et al. [17] used ceramic as LHP wick. Wan et al. [18] used a sintered metal fiber sheet as LHP wick. With optimization design to the condenser, the LHP was able to operate under 200 W heat load and the thermal resistance was 0.05 °C/W.

Biporous wicks, as another relatively new type of wick, also aroused wide interests in the relevant community. Li et al. [11] reported a couple of methods to fabricate biporous nickel wicks for LHP and determined optimal fabrication conditions. Xu et al. [7] modulated porous wick sintered on the heater wall to enhance pool boiling heat transfer. The modulated biporous wick significantly shortened the LHP startup time, and the wall temperature of evaporator was maintained at 63 °C under 200 W heat load and antigravity operation conditions. The calculated thermal resistance was 0.12 °C/W. Chen et al. [19] experimentally investigated the thermal performance of a miniature stainless-steel-ammonia LHP with biporous wick. The results demonstrated that the maximum heat load that the LHP could take was 130 W at −15 °C heat sink temperature, and the LHP thermal resistance was 0.33 °C/W. Specially, Liu et al. [20] reported a composite wick, which was of standard cylindrical design and actually consisted of two wicks: the primary wick was a sintered nickel powder wick and the secondary wick a stainless steel mesh. The working fluid of LHP was methanol. Their results showed that the LHP could start up under heat loads within a range of 20–160 W, and the evaporator temperature was kept below 85 °C when coolant temperature was −10 °C. The derived thermal resistance of LHP was within 0.46–2.28 °C/W.

Sintered copper powder wick and copper mesh wick are two typical wicks used in LHPs. However no direct comparison has been made to discern which is better. The present work designs and fabricates a stainless steel/water LHP and sets up an experimental system for the study of LHP heat transfer performance. The main goal is to experimentally study the effects of wick on LHP heat transfer performance including the startup performance, temperature oscillation characteristics, and the overall thermal resistance. The LHP wicks specially chosen for conducting the comparison study are right the sintered copper powder wick and copper mesh wick.

2. Experimental aspects

2.1. Characteristics of LHP wicks

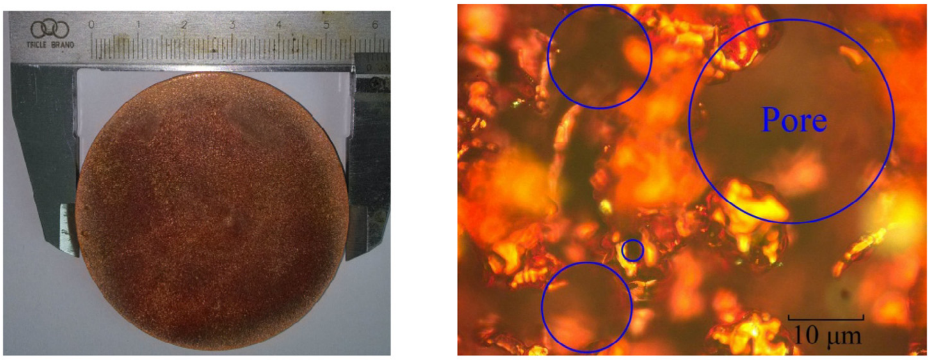
Wick is one important component of LHP, which affects the LHP performance mainly from the following two aspects: (i) the pores in the wick provide pathways for the working fluid to flow back into the evaporator; (ii) the partially liquid-saturated wick produces capillary force, which prevents the steam from penetrating the wick and entering the liquid line. We consider two wicks for comparison in the present work.

One is a sintered copper powder wick. Fig. 1 displays the appearance of the sintered wick. It is a thin circular flat plate of 58.5 mm diameter and 3 mm thickness. The digital photo shown in Fig. 1b was taken by a Keyence VHX-600 microscope camera. Directly from Fig. 1b, it is not difficult to get that the pore diameter is within 2.6~30 μm. To determine the porosity of the sintered wick is a relatively involved task. First, we measured the diameter (d_w) and thickness (l_w) of the wick by a Vernier caliper, and calculated the apparent volume $V_w\left(=\frac{\pi d_w^2 l_w}{4}\right)$. Second, we weighed the wick to get its mass (m) by an electronic scale. Third, we calculated the porosity (ε) with $\varepsilon = 1-\frac{m/\rho}{V_w}$, where ρ represents the intrinsic density of the wick material, i.e. copper here. The porosity of this sintered wick was calculated to be 77.5%. Further, the permeability (K_s) and effective thermal conductivity ($h_{s\text{-eff}}$) of the wick were calculated to be 2.1×10^{-11} m^2 and 4.6 W/m/K, respectively [21].

The other is a copper mesh wick. The wick is made of a 500 PPI (pores per inch) copper mesh, and contains about 31 layers of this mesh. Fig. 2 displays the appearance of the mesh wick. It is a thin circular flat plate of 58.6 mm diameter and 3 mm thickness. The Keyence microscope digital photo shown in Fig. 2b indicates that the diameter of the copper threads is about 26.2 μm. The effective pore diameter of the mesh wick was immediately determined to be about 35 μm and the porosity (ε_m) was calculated to be 66.5%. The permeability (K_m) and effective thermal conductivity ($h_{m\text{-eff}}$) of the wick were calculated to be 1.5×10^{-11} m^2 and 4.8 W/m/K, respectively [21–23].

2.2. Experimental system

As shown in Fig. 3, the experimental system consists of four subsystems: the LHP system, the heater system, the cooling system and the data acquisition system. The LHP is made of stainless steel. Choice



(a) (b)

Fig. 1. The sintered copper wick. (a) Normal photograph. (b) An enlarged photograph.