International Journal of Heat and Mass Transfer 107 (2017) 640–645

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Design and experimental study on a hybrid flexible oscillating heat pipe

Jian Qu *, Xiaojun Li, Yingying Cui, Qian Wang

School of Energy and Power Engineering, Jiangsu University, Zhenjiang, Jiangsu 212013, China

ARTICLE INFO

Article history:
Received 9 August 2016
Accepted 19 November 2016

Keywords:
Oscillating heat pipe
Flexible heat pipe
Thermal performance
Start-up

ABSTRACT

In this paper, a hybrid flexible oscillating heat pipe (FOHP), characterized by a hot/cold-end length of about 1.07 m, with the adiabatic section made of fluororubber materials and heating/cooling sections made of micro-grooved copper tubes was designed and fabricated. Deionized water was used as the working fluid at volumetric filling ratios of 50%, 60% and 70%. The thermal performance of FOHP with different structural styles created by the deformation of adiabatic section and changing the spatial arrangement of evaporator and condenser were experimental tested and compared. Results show that the FOHP could function well and exhibited highly spatial flexibility and acceptable heat transfer performance. The bending of adiabatic section partially degrades the start-up and heat transfer characteristics of FOHP, largely depend on the deformation extent. The FOHP provides a promising solution for the thermal management of some spatial complicated energy utilization systems.

© 2016 Published by Elsevier Ltd.

1. Introduction

Oscillating heat pipe (OHP) is a high efficiency heat transfer device normally made of capillary tubes and provides advantages of simple structure, low fabrication cost, fast response to high heat loads and good environmental adaptability. As a new member in the wickless heat pipe family, OHPs have received a continuing and growing interest in the past two decades [1] and considered as a promising solution in numerous industrial and commercial areas, such as heat recovery, drying, solar energy collecting, and electronics cooling [2].

To data most of OHPs are constructed using rigid materials such as copper, stainless steel and silicon [3–6] due to their benefits of easy fabrication, high thermal conductivity, and good workability, while they are sometimes not compatible with the requirement of foldable electronic devices and complicated confined spaces. Recently, flexible heat pipes, especially polymer heat pipes [7–11], have attracted considerable attention as they enable both flexibility and high performance. A conceptual OHP largely made of polydimethylsiloxane (PDMS) with the length, width, and inner diameter of 56, 50 and 2 mm, respectively, was fabricated and tested by Lin et al. [12] in 2009. During the fabrication process, two copper blocks were used as the evaporator and condenser. The experimental results indicated that the PDMS OHP has better thermal performance when charged with methanol as compared with that of ethanol. However, the thermal resistances of the OHP are relatively large, normally greater than 4.5 K/W. A similar PDMS OHP was experimental investigated by Ji et al. [13] using ethanol and Al_2O_3/ethanol nanofluid as the working fluids. Ogata et al. [14] developed a 0.34 mm-thick polymer OHP by forming with UV curable polymer resin on polyethylene terephthalate films. When electronic liquid HFE-7000 was used as the working fluid, the thermal resistance of the OHP reached a minimum value at a heat load of 4.11 W, which is comparable with that of a copper plate with the same thickness. Although all of above prototypes are miniature plate-OHPs and fully or partially fabricated by polymer materials, they have the deficiency of relatively higher thermal resistance, on the order of several K/W. Also, no bending experiments were conducted on these polymer OHPs to test the availability at flexural conditions. Although polymer OHPs was developed to some extent, the design of flexible oscillating heat pipe (FOHP) at a large version and work at a large range of bending angles has not been reported yet.

In this study, a FOHP with the adiabatic section made of fluororubber tubes was designed and tested at different spatial structural styles. Micro-grooved copper tubes were used to compose the heating and cooling parts because of their active role on the significant improvement of the OHP performance as first reported by our most recent study [15]. According to the experimentally test, it is found that the FOHP constructed by the combination of fluororubber and micro-grooved copper tubes exhibited highly spatial flexibility and attractive heat transfer performance, providing a possible option for the thermal management of some spatial complicated energy utilization systems, such as electric vehicle lithium-ion battery and telecommunication station.

---

* Corresponding author.
E-mail address: rjqu@mail.ujs.edu.cn (J. Qu).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.11.076
0017-9310/© 2016 Published by Elsevier Ltd.

2. Experimental

2.1. Design and fabrication of FOHP

Many factors influence the heat transfer performance of OHPs, such as working fluid, filling ratio, title angle, structure parameters, etc. To enhance the OHP performance, micro-grooved copper tube (4 mm outer diameter) with spiral structure having 12° helical angle and featured by 40 microgrooves inside was used to form the heating and cooling sections of an OHP, namely the evaporator and the condenser. With the aid of microgrooves, the OHP can significantly enhance the capability to transfer both of sensible and latent heat, avoid large temperature fluctuations and obtain lower evaporator temperature and thermal resistance [15]. Moreover, the adiabatic section of the OHP was fabricated by fluororubber tubes. To match the micro-grooved tube size and jointly compose the OHP, the fluororubber tube with an outer/inner diameter of 6/4 mm was used.

In this study, fluororubber 246 was selected. Compared to other polymers that have been used as the connecting materials in flexible heat pipes, this fluororubber provide the advantages of better heat resistance, wide range of working temperature (-50 to 200 °C), good shockproof capability, lower gas permeability, and excellent bendability [16]. Noted that the high temperature stability of this fluororubber is also attractive because it can maintain good elasticity after being heated 16 h by 350 °C hot air.

After being fully washed by absolute ethyl alcohol, the copper and fluororubber tubes were then bonded together by an adhesive at room temperature, composing the FOHP ultimately. The amplificatory inner surface and cross section of the micro-grooved tube are present in Fig. 1. Its internal equivalent diameter can be estimated by [17]:

$$D_{\rm h} = \frac{4A\cos\alpha}{NS} \tag{1}$$

where A is the cross-sectional area infiltrated by pipe flow inside, S is the perimeter wetted of a single micro-groove and channel taken perpendicular to the axis of groove, and α and N are the helix angle and number of micro-grooves, respectively. According to the geometrical parameters given by Fig. 1, the internal equivalent diameter of the copper micro-grooved tube is about 2.03 mm.

2.2. Experimental setup

The experimental setup is illustrated in Fig. 2, mainly consisting of a FOHP assembly, a heating unit, a cooling unit and a data acquisition system. The FOHP fabricated by fluororubber tube and microgroove copper tube has seven turns, and the lengths of the evaporator, adiabatic and condenser sections are 80, 870 and 120 mm, respectively. So the total length of the hybrid FOHP is up to about 1.07 m.

As illustrated in Fig. 2, the evaporator of the FOHP was electrically heated by a nichrome wire with a diameter of 0.3 mm. The heating wire packaged by a soft insulating tube was wrapped uniformly around the evaporator tube surface and connected to an AC voltage transformer served as the power supply unit. Then, the

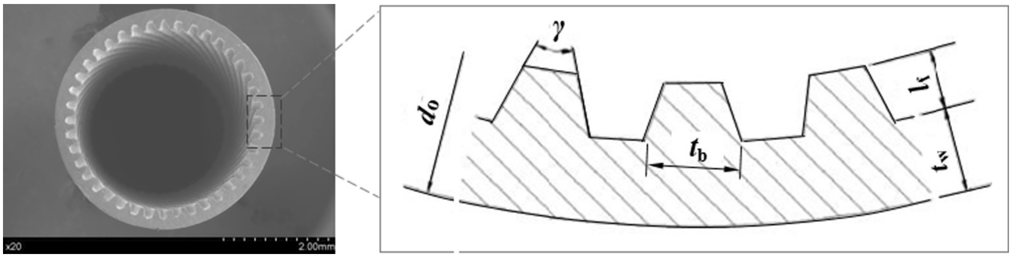

Fig. 1. Cross section image of a micro-grooved tube (γ = 40°, $l_{\rm f}$ = 0.12 mm, $t_{\rm b}$ = 0.18 mm, $t_{\rm w}$ = 0.22 mm, $d_{\rm o}$ = 4 mm).

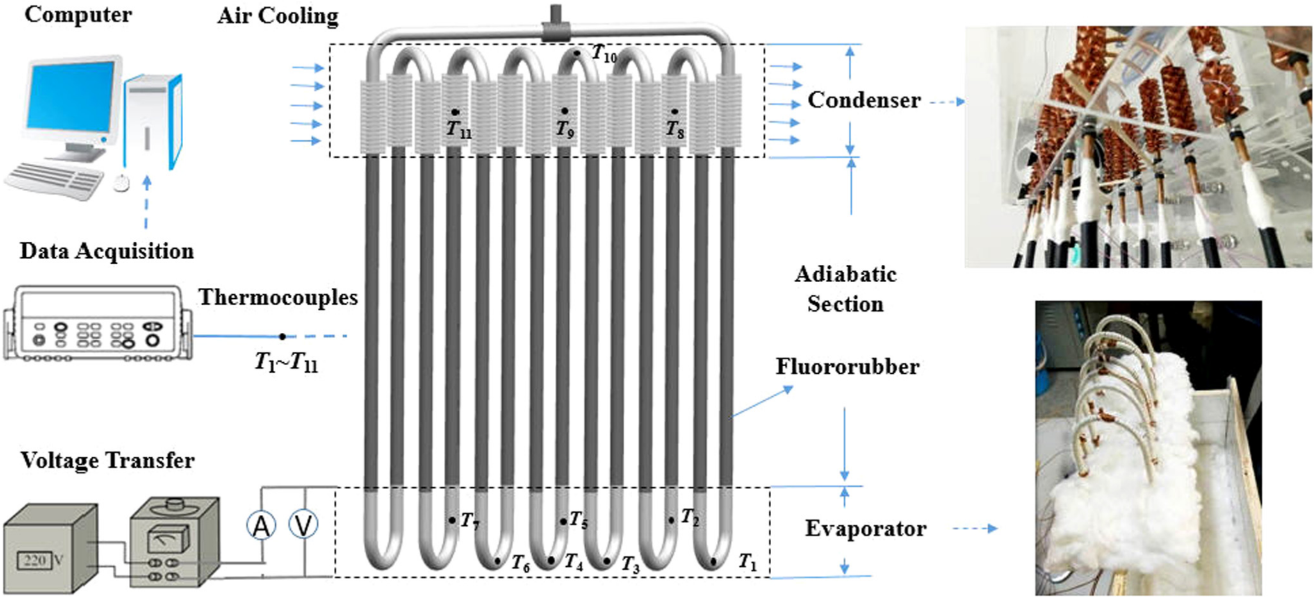

Fig. 2. Schematic diagram of the experimental setup and local images of the evaporator and condenser regions.

Download English Version:

https://daneshyari.com/en/article/4994617

Download Persian Version:

https://daneshyari.com/article/4994617

Daneshyari.com