International Journal of Heat and Mass Transfer 72 (2014) 378–387

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Experimental investigation and visual observation of loop heat pipes with two-layer composite wicks

Jiayin Xu, Li Zhang *, Hong Xu, Jie Zhong, Jin Xuan

State-Key Laboratory of Chemical Engineering, School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, China

ARTICLE INFO

Article history:
Received 2 April 2013
Received in revised form 4 December 2013
Accepted 3 January 2014
Available online 2 February 2014

Keywords:
LHP
Flat evaporator
Cu–Ni composite wick
Heat leak
Evaporation

ABSTRACT

A LHP which had a flat disk-shaped evaporator with a transparent cover was manufactured to observe the flow motion in the evaporating zone and the compensation chamber, and two-layer Cu–Ni composite wicks were also proposed to compare the thermal performance with a copper wick, the total thickness of all wicks was 5 mm. It was observed that there were bubbles accumulated on the upper side of the copper wick during the incipience of the start-up, and heat pipe effect was shown during the operation at the heat load of 120 W, due to the high thermal conductivity of the copper material. In addition, the Cu3Ni2 wick, which has 3 mm thickness of copper layer attached at the heat source to enhance the evaporation efficiency and 2 mm thickness of the nickel layer facing to the compensation chamber, is the optimal wick for the LHP. The LHPs with a Cu3Ni2 wick could start fast in about 170 s, and the evaporator wall temperature could be maintained under the allowable temperature of 85 °C at the heat load ranged from 30 to 120 W. It can be concluded that an optimal wick for the LHPs is that the balance between the efficient evaporation close to heat source and low back conduction problem (heat leak) should be achieved simultaneously.

1. Introduction

Loop heat pipe (LHP) is a passive cooling device used in space applications and compact electronics. It was firstly introduced by Russian scientist Maydanik [1] based on the conventional heat pipe in 1972. After years of development, many types of LHP have been proposed. Besides the cylindrical evaporator [2–4], flat evaporator was designed to fit the heat source properly. These flat evaporator could be divided into disk-shaped evaporator [5–8], rectangular evaporator [9–11] and flat-oval evaporator [12,13] according to the evaporator shape. Although the LHP has been widely studied and used on the thermal management, it is still hard to figure out the phase change behavior in the evaporator and the condenser only with the help of the traditional temperature measurement. Hence, it is necessary to make the LHP visualization to have a deep understanding on the phase change in the LHP. A transparent evaporator made of Pyrex glass was manufactured by Junwoo et al. [14] to observe the phenomena including vapor formation, nucleate boiling and evaporation. A LHP was designed by Wang et al. [15] to enable the visualization at the all of parts of the LHP except the evaporator. A bore scope was inserted into the liquid core to study the influence of the liquid level on the LHP start-up by Entremont [16]. Recently, visual investigations of the condensation and redistribution of the working fluid in the LHP have been carried out by Bartuli et al. [17].

In addition, wick materials such as nickel [3], stainless steel [18] and ceramic [19] have always been used to address the heat leak during the operation of the LHP because of low thermal conductivity. Although it is well known that copper is more efficient in heat exchange, the start-up process for the LHP with a copper wick is slower than the LHP with a low thermal conductivity wick. Thereby, for quite a long time, copper is not considered as a suitable material for making the capillary wick because of massive heat leak resulted from high thermal conductivity. Since 2011, however, more and more literatures [20,21] have proved that the copper–water LHP has the capability to meet the demand for the thermal management of electronics. Many improvements on the LHP design have also been proposed to relieve the influence of the heat leak by increasing the copper wick thickness [11], using a large diameter vapor line [20] and charging the LHP with a high ratio [22]. The former two methods can improve the start-up performance by making a large temperature difference between the two sides of the wick or making the pressure drop low in the vapor line, while the latter one can keep the wick saturated to relieve the heat leak. Although these improvements are really effective to alleviate the heat leak, the optimal wick for the LHP should be compromised between the efficient heat exchange in the evaporator and low heat leak [5] in order to have a fast start-up and a high heat transfer capacity.

---

* Corresponding author. Tel.: +86 021 64252847; fax: +86 021 64253810.
E-mail address: lzhang@ecust.edu.cn (L. Zhang).

0017-9310/$ - see front matter Crown Copyright © 2014 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.01.016

Nomenclature

Cp	liquid specific heat, J/(kg K)
h_{fg}	latent heat for vaporization, J/kg
m	mass flow rate, kg/s
ΔP	pressure difference, Pa
Q	heat input, W
$Q_{e,vap}$	heat for evaporation, W
$Q_{e,cc}$	heat leak, W
R	thermal resistance, °C/W
T	temperature, °C
ΔT	temperature difference, °C

Greek symbol

ε	porosity

Subscripts

bw	bottom side of the wick
cc	compensation chamber
ci	inlet of the condenser
co	outlet of the condenser
cond	condenser
e	evaporator
ez	evaporating zone
ew	evaporator wall
LHP	loop heat pipe
uw	upper side of the wick
v	vapor

In this paper, the visualizations of the evaporating zone and the compensation chamber are realized to observe the evaporation and the flow in the evaporator. Besides that, a two-layer composite wick made of copper and nickel powders is proposed, and the copper side is attached on the heat plate to promote the evaporation and the nickel side is close to the compensation chamber to address heat leak. In order to achieve the balance of the efficient evaporation and low heat leak, the optimal thickness for two layers is studied. The optimal one is also compared to a LHP with a copper wick (single layer).

2. Experimental apparatus and procedures

2.1. Experimental set-up

The scheme of the LHP and the detail of the temperature measurement points were presented in Fig. 1. The LHP consisted of an evaporator, a capillary wick, two transport lines for liquid and vapor flows, a condenser with a fan and an electric heater. The evaporator has a flat disk shape with the diameter of 56 mm and the thickness of 30 mm in all. As shown in Fig. 2, the evaporating zone and the compensation chamber were separated by the capillary wick. The evaporator was sealed by using an O-ring seal between the evaporator cover and the brass plate with a flange bolt connection. Another smaller O-ring was mounted between the evaporator cover and the upper side surface of the capillary wick to avoid any vapor bypass to the compensation chamber. The evaporator cover was made of transparent polycarbonate plastic to realize the visual observation of the flows in the evaporating zone and the compensation chamber, and the heat leak results from the thermal conduction of the evaporator envelop can also be neglected owing to the low conductivity of polycarbonate. There were 6 longitudinal grooves with the cross section of 2 mm width × 2 mm depth machined on the brass plate, which served as vapor removal channels and also conducted heat from the brass plate to the bottom face of the capillary wick. Two-layer composite wicks with the total thickness of 5 mm were used in the present study, which had a copper layer to be the bottom face of the wick for efficient evaporation and a nickel layer for alleviating the heat leak to the compensation chamber. The compensation chamber was 9 mm in thickness and accommodated the excessive working fluid to keep the wick wet. Two transport lines were 4 mm in internal diameter, and the lengths were 140 mm for vapor flow and 70 mm for liquid flow. In order to dissipating heat from the evaporator, a fin-and-tube condenser made of copper was applied as shown in Fig. 3. The pipe in the fin-and-tube condenser was also 4 mm in internal diameter, and the length was 640 mm. A 0.03 mm thick nickel-chrome serpentine heater was fabricated by wire-cutting, and the heating power was controlled by a DC power supply (Agilent N5769A). The heat power applied to the evaporator was measure by a digital multimenter (Agilent U3402A) with accuracies of 0.012% and 0.2% for voltage and current respectively. The brass plate and the heater were bonded together with high conductive Omega-bond 200 for electric insulation. The heating area of the evaporator was 7.07 cm^2 (30 mm diameter). Thermal insulation from the ambient was realized by a fiberglass layer clinging to the brass plate and the transport line for vapor flow. Deionized water was selected as the working fluid.

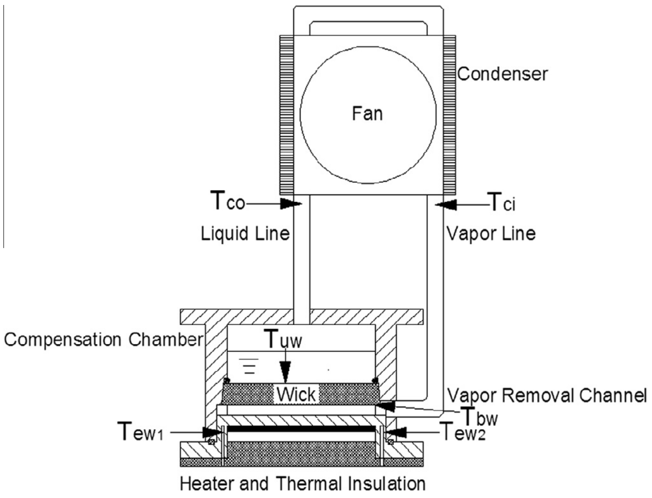

Fig. 1. Scheme of the LHP and detail of the temperature measurement points.

Six T-type thermocouples were applied for temperature measurement. Two were sheathed thermocouples (1 mm diameter, Omega) for measuring wall temperatures of the evaporator (T_{ew1} and T_{ew2}), and these two temperature readings were averaged to be considered as T_{ew}. The other thermocouples (0.38 mm diameter, Omega) were inserted into the LHP to measure the inlet and outlet temperatures of the condenser (T_{ci} and T_{co}) for monitoring the LHP start-up, and the upper and bottom surfaces temperatures of the wick (T_{uw} and T_{bw}) to compare heat leak resulted from different wick.

2.2. Wicks for experiment

In present study, several composite wicks with two soldered layers made of copper and nickel powders were ready for the