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Experimental study on the operating characteristics of a flat bifacial evaporator loop heat pipe

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ABSTRACT

There is growing demand for highly efficient heat transfer devices having excellent performance, operational stability and low power consumption. Although loop heat pipes satisfy these requirements, conventional loop heat pips have limited application to flat heat sources due to their mostly cylindrical evaporator shape. To overcome this limitation, various types of flat evaporator loop heat pipes have been developed, though their operational reliability is still uncertain. In this work, we focused on the development of a flat bifacial evaporator loop heat pipe, and its operating characteristics at transient and steady states are discussed in detail.

1. Introduction

Loop heat pipes (LHPs) are highly promising two-phase heat transfer devices and compared to similar two-phase devices such as heat pipes and capillary pumped loops, they have superior heat transfer capacity, reliable operation in a gravitational field and structural simplicity. This is due to structural differences such as the wick being located only in the evaporator and the incorporation of a compensation chamber into the evaporator. With these advantages, the LHPs have mostly been used in challenging fields such as space technologies as almost the only measure for the thermal control of heat generating devises of some critical missions. However, these days, there have been widespread efforts to extend the sphere of the applications of these devices to the land based (terrestrial) applications, such as electronic equipment cooling and heat recovery devices, which require highly efficient heat transfer capability too [1–13].

In electronics cooling, the primary requirements imposed on the heat transfer devices are low thermal resistance between the heat acquisition and rejection sites, and structural flexibility for use in the tortuous paths between those sites. Although conventional LHPs satisfy these requirements, the additional thermal resistance induced by their cylindrical evaporators (which require supplementary intermediaries called saddles) leaves room for improvement. In addition, since most heat sources have flat thermo-contact surfaces and are closely packed, the development of LHPs with flat evaporators having symmetric heat absorbing surfaces is of primary concern [1,5,14–16]. Recently, a primitive planar bifacial wick structure and corresponding flat bifacial evaporator loop heat pipe (FBELHP) were devised and tested, and performed satisfactorily at a horizontal (or zero) elevation and tilt at which the condenser, evaporator and compensation chamber were level [16]. However, despite the successful operation of this device at a horizontal elevation and tilt, there is still no guarantee of successful operation at other elevations and tilts at which the effect of gravity is significant.

The effect of gravity, more specifically of elevations and tilts, is considered to be one of the most important factors influencing LHP performance. It is generally known that at an adverse elevation, with the condenser located below the compensation chamber, the operating temperature of the LHP is increased. This is due to the increased hydrostatic head which increases saturation pressure and temperature differences across the wick. This results in increased heat leak to the compensation chamber and a higher saturation temperature of the compensation chamber [15,17–22]. Under the effect of gravity, especially at an adverse elevation at which the detrimental effect of gravity is severe, reliable operation of the FBELHP is not guaranteed due to the rather inefficient wick structure (planar bifacial wick) separating two phases. In this situation, the formation of the required saturation pressure difference across the wick is uncertain. In addition, the lack of data for these conditions necessitates further investigation into the operating characteristics of the FBELHP under various elevations and tilts.

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Nomenclature

C	thermal conductance	cd	condenser
c_p	isobaric specific heat	*cond. out*	condenser outlet
g	gravity acceleration	*evap*	evaporator
h	height	g	gravitational
$\dot{m}$	mass flow rate	l	liquid phase
P	pressure	ll	liquid transport line
R	thermal resistance	*loss*	loss
$\dot{Q}$	heat load	*sat*	saturation
T	temperature	*sc*	subcooling
		sink	heat sink
Greek symbols		*th*	thermal
φ	phase	*vg*	vapor removal grooves
ρ	density	*vl*	vapor transport line
Subscripts			
ba	bayonet		

In this work, the planar bifacial wick was modified to improve sealing structure between the two phases as poor sealing is thought to be the main obstacle reducing the heat transfer capacity of the FBELHPs. Using this modified wick structure, experiments were carried out to study the effects of parameters such as elevation and heat sink temperature on the transient and steady state operation of the FBELHP.

2. Experimental parameters

Fig. 1(a) and (b) shows the schematic of the FBELHP and the corresponding thermodynamic operation curve. These figures clearly show the effects of gravity shown as the hydrostatic head terms (ρgh) on the liquid transport line and the heat sink temperature which influences the condenser outlet temperature (T_4). The hydrostatic head, which accounts for the effect of gravity, is defined as the net liquid hydrostatic head along the liquid transport line. This net hydrostatic head corresponds to the height difference between the two-phase interfaces of the compensation chamber and the condenser, and is given as follows:

$$\Delta P_g = \rho_l g(h_1 - h_2) \tag{1}$$

The magnitude and sign of the net liquid hydrostatic head affects the operation of the LHPs according to the relative positions of the compensation chamber and the condenser. The role of this term is clearly shown in the following pressure balance equation:

$$\begin{aligned}\Delta P_{sat} &= P_{sat,1} - P_{sat,7} = \Delta P_{loss} \\ &= \Delta P_{vg} + \Delta P_{vl} + \Delta P_{cd} + \Delta P_{ll} + \Delta P_{ba} + \Delta P_g\end{aligned} \tag{2}$$

As is evident in Eq. (2), depending on the sign of the hydrostatic head term (ΔP_g), the hydrostatic head provides opposing, neutral, or favorable effect on the driving force of the LHP and is correspondingly termed an adverse, horizontal (or zero) or favorable elevation. For each configuration, the condenser locates below, levels with, or locates above the compensation chamber. Thus in our experiments, to see the effect of elevation on the transient and steady state performance of the FBELHP, we changed the elevation from favorable to adverse. Another factor related to gravity is tilt which is the relative position of the evaporator to the compensation chamber, and affects the liquid phase working fluid supply to the wick. In this work, to exclude the thermosyphon effect, the tilt was fixed favorable only where the evaporator was placed below the compensation chamber.

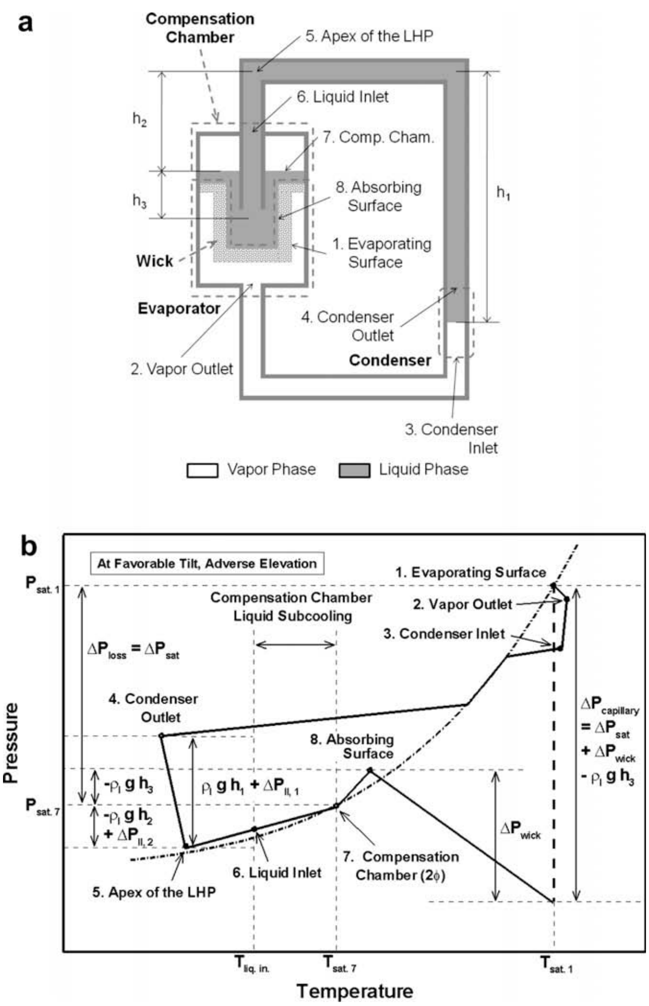

Fig. 1. Schematic and corresponding thermodynamic operation curve of the LHP. (a) Schematic of the LHP. (b) Thermodynamic operation curve of the LHP.

Another influential parameter is the heat sink temperature. As shown in Fig. 1(b), the heat sink temperature affects the condenser outlet temperature which dictates the liquid subcooling of the compensation chamber. This liquid subcooling is defined as the subcooling below the local saturation temperature of the working