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Experimental study on loop heat pipe with two-wick flat evaporator

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ABSTRACT

A flat-type loop heat pipe (FLHP) is considered promising for applications in the field of thermal control and electronic cooling owing to its many advantages such as high heat transfer capability with small temperature difference, easy installation, and lack of moving parts. However, it suffers from drawbacks such as high back-conduction in the evaporator. Many studies have aimed to improve the performance of FLHPs by changing the working fluid or porous materials. In a loop heat pipe (LHP) with a flat evaporator, the compensation chamber (CC) is usually in the vapor–liquid two-phase state owing to backward conduction of the wick and side-wall conduction of the evaporator. When the heat load is in a certain range, bubbles are generated and then annihilated in the compensation chamber, and the temperature and pressure fluctuate, causing unstable LHP operation. To eliminate or reduce back-conduction in the flat evaporator, this study develops a loop heat pipe with two primary sintered nickel powder wicks arranged in an evaporator made of brass and using methanol and acetone as the working fluids. The startup and operation are studied under variable conditions with different heat loads. The experimental results show that our novel LHP can start up successfully and operate in a wide heat load range of 10–170 W. When the temperature of the contact surface between the simulated heat source and the evaporator does not exceed 90 °C, the maximum heat load can reach 170 W, which corresponds to a heat flux of 17.7 W/cm^2.

1. Introduction

A loop heat pipe (LHP) is a type of efficient heat transfer device whose operating principle is based on the evaporation and condensation of a working fluid [1]. It utilizes the pressure difference in the meniscus of the porous wick of an evaporator to ensure a working fluid cycle. The porous wick is only arranged in the evaporator of the system to allow the evaporating liquid to spread out on the evaporating surface as much as possible, so as to not only provide a driving force but also reduce thermal resistance.

Compared with a conventional cylindrical LHP, a flat-type LHP (FLHP) can be better assembled with the heating element, thus increasing the contact area with the heat source and heating the wick more evenly. From the viewpoint of the field synergy principle, in an FLHP, the angles of the velocity and the temperature gradient are smaller than that of an LHP with a cylindrical evaporator, and the heat transfer efficiency is better [2].

Many FLHPs have been studied experimentally and reported to show good performance [3–8]. Our laboratory, too, has conducted extensive experimental studies on FLHPs in recent years [9–12]. It has been observed that in a certain range of heat load, temperature fluctuations may occur during the operation of an LHP. Many studies have aimed to analyze and explain these fluctuations. Maydanik et al. [13] observed that pulsations of the operating temperature depend on the amount of working fluid, device orientation in the gravity field, and conditions of condenser cooling, and intense pulsations arise from the lack of a working fluid when a hot condensate or vapor bubbles periodically penetrate the compensation chamber (CC). Ku et al. [14] believed that the CC temperature controls the loop operating temperature and that the oscillation of the CC temperature further amplifies temperature oscillations in the rest of the loop. Moreover, all loop components are thermally and hydrodynamically interrelated. Zhang et al. [15] experimentally found that temperature fluctuations usually appear under small or large heat load. For startup with a liquid-filled evaporator, the working fluid in the wick may evaporate at small heat load, causing a temperature fluctuation at the condenser inlet and eventually leading to the steady-state operating temperature being higher than normal. The temperature fluctuation at the condenser outlet is due

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to the mismatch between the amount of working fluid and the reservoir volume. Zhang et al. [16] conducted an experimental study on a miniature LHP and found that the LHP can start up at a heat load of 15 W with temperature oscillation, and the oscillating frequency of the temperature rises and amplitude decreases with increasing heat load. They concluded that temperature oscillation is caused by insufficient driving force and phase distribution of the working fluid in the CC under different heat loads.

In addition, many studies have aimed to improve the LHP performance and adapt to the needs of different working conditions. Bai et al. [17] proposed a novel evaporator to improve the operating performance and reliability of the LHP by reducing heat leakage from the evaporator to the CC. Hoang et al. [18,19] combined a CPL(Capillary pumped loop) and an LHP into one loop by exploiting their individual advantages while eliminating their disadvantages. When the secondary pump was activated, it created a fluid flow from the evaporator pump reservoir to the condenser and thereby removed an amount of vapor in the reservoir. The more the amount of vapor mass that was removed from the reservoir, the lower the loop saturation temperature would drop. Joung et al. [20,21] developed a thin planar bifacial evaporator with a bifacial wick structure for application to closely packed heat sources such as fuel cells. Furthermore, they modified the planar bifacial wick to improve the sealing structure between the two phases, as poor sealing is thought to be the main obstacle reducing the heat transfer capacity of flat bifacial evaporator LHPs (FBELHPs).

When using copper as a flat LHP external structural material, the side-wall heat conduction from the evaporator warms the CC, and taking the heat leakage through the porous wick into account, the temperature of the CC and the back of the evaporator is high and the CC is usually in a vapor–liquid two-phase state [22]. As a result, the pressure in the CC is high, leading to an increase in the operating resistance of the system [23] and possibly to the dramatic generation and annihilation of bubbles in the CC, in turn leading to large temperature and pressure fluctuations. Therefore, this study proposes an LHP with a two-wick flat evaporator to weaken or eliminate the fluctuations. The operating performance of this novel LHP is studied, and an effective approach for improving the operating capability is developed.

2. Experimental system and operating principle

A new flat bifacial evaporator with two wicks is designed in this study, as shown in Fig. 1. Two primary wicks are assembled in the heating surface and the back of the evaporator. Between the two wicks, a circular metal mesh, which could also be considered a secondary wick, is used to form a sealed space for the CC. The metal mesh can supply the liquid for the wick in the back of the evaporator. Owing to contact with high-pressure vapor, the pore size of the metal mesh should be able to prevent the vapor from recoiling into the CC.

In this construction of the LHP with a two-wick flat evaporator, the CC is sealed in the ring-shaped stainless steel wire mesh. The wicks can lower the CC temperature owing to the additional thermal resistance between the side wall and the fluid in the CC, so as to reduce the generation and annihilation of bubbles and the flow resistance of the evaporator inlet. With the wick in the back of the evaporator, vapor could generate at this location and lower the temperature there, thereby absorbing part of the heat load to increase the system's maximum operating heat load. Moreover, owing to the increased evaporator surface, the pressure in the evaporator increases rapidly, which is beneficial to the startup of the LHP.

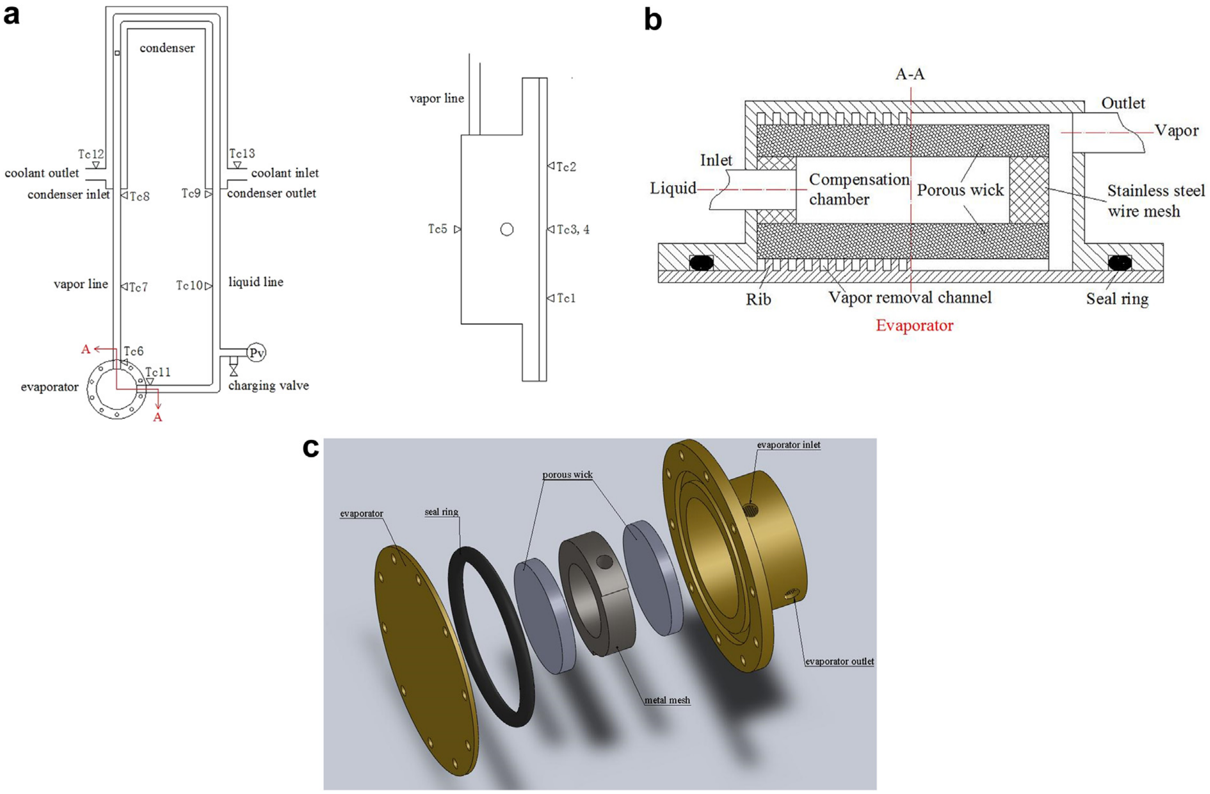

Fig. 1. Schematics of the LHP and the configuration of the evaporator. (a) Outside view of the LHP and the evaporator, and the placement of the thermocouple points. (b) Cross section of the LHP evaporator. (c) Exploded view of evaporator.