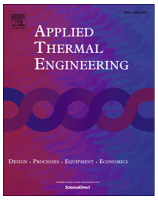
Applied Thermal Engineering 130 (2018) 10–16

Contents lists available at ScienceDirect

Applied Thermal Engineering

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



Research Paper

Experimental investigation of the operating characteristics of a hybrid loop heat pipe using pump assistance

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HIGHLIGHTS

- A new design of hybrid loop heat pipe using pump assistance.
- Pump was only activated when the dry-out will took place.
- When the pump turned on, it will successful to prevent the dry-out.

ARTICLE INFO

Article history:
Received 19 June 2017
Revised 30 October 2017
Accepted 1 November 2017

Keywords:
Hybrid loop heat pipe
Pump assistance
Dry-out
Start-up

ABSTRACT

A loop heat pipe (LHP) is one of the two-phase cooling technologies used in passive cooling systems. The LHP is an efficient heat transfer device, but its extreme power density can cause dry-out at the evaporator. Many researchers have predicted that passive devices will not be able to meet future cooling challenges because of this limitation. The objective of this research is to design a modified LHP that overcomes the dry-out problem by adding a diaphragm pump to accelerate fluid transportation (called a hybrid loop heat pipe, HLHP). The pump installed on the liquid line is coupled with a reservoir. The developed HLHP works passively using wick capillary pressure when there is no sign of dry-out. When dry-out occurs, the pump is activated via diaphragm pumping and has a temperature controller. Thus, the working fluid is circulated by both the capillary force and driving force of the diaphragm pump during the heat-transfer process. The operating characteristics of the HLHP under a variety of heat load supply and low-power start-up conditions have been investigated. The experimental results indicate that the installation of a diaphragm pump in a modified LHP system can prevent the occurrence of dry-out in the evaporator and significantly reduce the evaporator temperature.

1. Introduction

One method of thermal management is to use a loop heat pipe (LHP), which is a two-phase heat transfer unit that exploits the latent heat of vaporization of a working fluid. The LHP has the ability to absorb and transfer large amounts of heat by evaporating the working fluid in the evaporator and allowing condensation in the condenser without any fluid machinery [1–3]. It is known that two-phase heat transfer enables more heat to be transferred than when using single-phase sensible heating of a fluid. The latent heat of vaporization (Δh_{fg}) of water, for instance, can be two orders of magnitude greater than the sensible heat ($C_p\ \Delta T$) of the cooling mechanism in a single-phase system of the same size. This makes two-phase heat transfer superior in terms of the heat transport capacity. In addition, the effect of boiling can increase the heat absorption per unit volume of liquid, and boiling also produces a heat transfer coefficient that ranges from 2.5 to 100 kW/m^2-K [4–9]. Thus, the two-phase cooling system is excellent in terms of high heat flux removal, with minimal superheating and isothermal heat transfer in the evaporator [10].

To operate an LHP, heat can be continuously absorbed and released over a considerable distance through two-phase isothermal transfer at the saturation temperature [11]. However, the LHP may not be able to meet the future challenges of cooling because of the inherent limitations of the capillary pump force: the high heat flux, transport distance, and multiple heat source capabilities [12]. High heat flux devices can be found in many systems, such as radars, lasers, microwaves, and avionics [13].

In recent years, many interesting studies have attempted to manage the thermal characteristics of LHPs in electronic systems, and numerous experiments and theoretical analyses have been carried out to improve the performance of LHPs. According to the results of studies on thermal management, it is important to modify

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https://doi.org/10.1016/j.applthermaleng.2017.11.007
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LHPs that are used as cooling systems in high heat flux devices. One modification, known as a hybrid loop cooling system, incorporates mechanical pumping (active) with capillary pumping (passive). Thus, a hybrid two-phase loop combines the high heat flux and robust operation of two-phase loop conventional pumping with the simplicity and reliability of the capillary mechanism [6,14]. Using a mechanical pump, the limits of the capillary-driven LHP system can be extended, although the total pressure head of capillary (passive) and mechanical pumping (active) should remain greater than all of the pressure drops in the system [10].

A number of experimental studies on hybrid loop cooling systems have been conducted. For instance, Park et al. [8,12,15,16] studied pump-assisted and capillary-driven (hybrid) two-phase cooling loops using a single evaporator and parallel dual-evaporators. In another work [10], they conducted an investigation of the hybrid two-phase loop and observed how the system handled multiple and different heat sources, how they interacted with the evaporator, and how they influenced one another in different configurations, both in series and in parallel. Furthermore, they described the limitations of the cooling performance for each configuration. Sarraf et al. [14] demonstrated the use of a hybrid capillary pump loop for high-temperature electronics, and characterized the system at lower temperatures. The results indicate that the system was able to eliminate heat flux at up to 67 W/cm^2. Zhang et al. [17] conducted an experiment on a pump-driven loop heat pipe. They used a canned motor pump complete with a liquid reservoir charged with R22 as the working fluid for data centre cooling. They investigated the relationship between the mass flow rate of the working fluid and the thermal performance of the system. The results show that the mass flow rate slightly influenced the heat transfer rate. The relationship between the heat transfer rate and indoor–outdoor temperature difference was linear. Jiang et al. [18] investigated a two-phase loop that combined active and passive systems, called the pump-assisted capillary loop phase change. This was designed to overcome the weaknesses of temperature oscillations and the limited range of heat transfer in the LHP. The test results show that the system had a very fast response to variable heat loads, with no obvious temperature oscillation detected. In another study [19], they investigated the start-up characteristics of a pump-assisted capillary phase change loop. This was tested under different operational conditions, and several start-up characteristics were classified and analysed. The results indicate that there were three different modes, wick flooding, thin-film boiling, and vapour superheating, and suggest that the pre-conditions in the evaporator have a notable impact on the start-up characteristics.

The results of the above research represent a significant advance over the state-of-the-art in hybrid loop heat pipes. In this study, an LHP is modified with a diaphragm pump assembly in its liquid channel to give a hybrid loop heat pipe (HLHP). Our design is slightly different from other designs, which use continuously activated pump assistance. Our HLHP works as a passive cooling unit when the heat load and other parameters do not produce dry-out. However, if there is any sign of dry-out, the pump is activated. Thus, HLHP can be operated under two different conditions.

2. Methodology

In this research, an HLHP was developed by integrating a pump with an LHP. The study included the design, manufacture, and performance testing phases of the HLHP.

2.1. Design and manufacture of HLHP

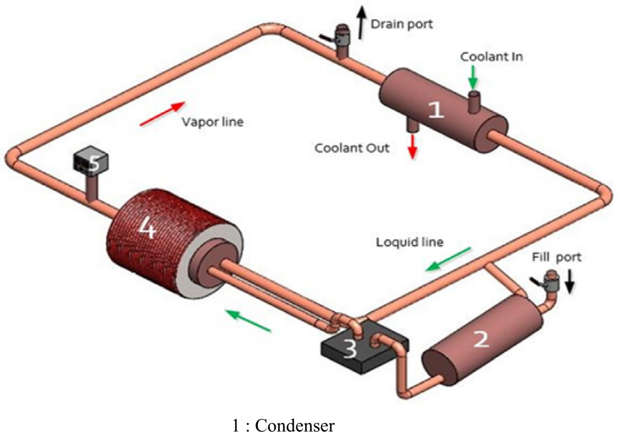
The HLHP prototype was designed by modifying the basic LHP. The HLHP used 5-mm-diameter copper pipe for the vapour line and liquid line, both with a length of 400 mm. The design principle of the HLHP is depicted in Fig. 1 [9]; the simple configuration of the system has an evaporator, condenser, reservoir, and diaphragm pump. The reservoir provides enough space to accommodate the liquid which can be used when needed. Therefore, the fluid from the condenser can be drawn into the evaporator in two ways, namely, by simple capillary pumping or a combination of capillary pumping and diaphragm pumping. The condenser is a tube in the tube heat exchanger that is constructed of a 70-mm copper pipe with an inside diameter of 23 mm. It has a counter flow fluid direction that has two ports, a coolant inlet and an outlet, each with a diameter of 10 mm. To ensure the availability of liquid for transfer to the evaporator, the HLHP was also equipped with a reservoir placed on the liquid line and connected to the pump. The reservoir was made of copper pipe with an inside diameter of 23 mm and length of 65 mm. In the liquid line, a forked pipe was created in which one branch went directly into the evaporator and the other deflected 90° into the inlet pipe of the reservoir. The outlet pipe at the bottom of the reservoir was connected to the pump, and the liquid pipe from the pump went directly into the evaporator. The addition of the diaphragm pump enabled fluid to be pumped into the evaporator when needed. The pump requires 0.3 W of power and has a capacity of 20 ml/min. The pump was expected to speed up the return of the working fluid to the evaporator and produce better fluid circulation.

The evaporator was formed from a cylindrical model made of copper pipe, with a length of 65 mm, inner diameter of 23 mm, and wall thickness of 1.2 mm. To prevent vapour flowing back into the liquid line, the wick extended 30 mm into the two pipes of the evaporator. Fig. 2 shows the pipe installation of the HLHP evaporator. The wicks were formed by sintering using 300-μm copper powder particles.

2.2. Performance testing of the HLHP

2.2.1. Working fluid filling procedure in the HLHP

In charging the working fluid into the HLHP, it is important to check for leaks at each connection. A compressor was used to find any leaks by applying pressure up to 4 bar (400 kPa). The HLHP was then started to ensure that there were no leaks in any part. A vacuum was created in the HLHP before charging the working fluid to ensure there were no non-condensable gases in the system [20]. Then, the working fluid entered the HLHP through the filling



1 : Condenser
2 : Reservoir
3 : Diaphragm pump
4 : Evaporator
5 : Pressure sensor

Fig. 1. Design of Hybrid loop Heat pipe.