Applied Thermal Engineering 91 (2015) 953–962

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research paper

Effect of liquid charging process on the operational characteristics of pump-assisted capillary phase change loop

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HIGHLIGHTS

- Two different liquid charging methods were designed.
- Comparisons of the operational characteristics of pump-assisted loops were made.
- The vaporization temperature decreased due to the optimized charging method.
- Loop with the optimized charging method had a superior performance under low heat loads.

ARTICLE INFO

Article history:
Received 15 June 2015
Accepted 17 August 2015
Available online 4 September 2015

Keywords:
Pump-assisted
Phase change
Vaporization temperature
Liquid charging method

ABSTRACT

In this work, two different liquid charging methods are designed to use in different pump-assisted capillary phase change loops. The aim of present work is to investigate the impact of the liquid charging processes on the operational characteristics of the loop. For the two pump-assisted capillary loops, the loop structure and the main parameters of the components keep the same. In addition, methanol is used as the working fluid in both loops. The experimental results demonstrate that the vaporization temperature of the loop 2 has a notable decrease due to the optimized liquid charging process. The corresponding thin film boiling in the evaporator of loop 2 occurs even though a lower heat load is applied. Meanwhile, with a high heat load applied to loop 2, the unique vapor superheating in the vapor chamber is observed. Comparing the heat transfer performance between the loops, the loop 2 presents a superior capability at low heat loads, while loop 1 can transfer a higher heat load for the upper bound of the heater surface temperature. For both of the loops, the evaporator thermal resistance, if not included the heat load of 10 W at a pumping power of 2 W in loop 2, varies between 0.15 K/W and 0.3 K/W.

1. Introduction

Two-phase cooling is proven to be a highly effective thermal solution for dissipating heat from electronic devices, as compared to the single-phase fluid loop [1,2]. The merits of two-phase cooling pertain mainly to providing better heat transfer performance, lower thermal resistance, and higher temperature uniformity [3,4]. As a representative two-phase cooling system, loop heat pipes (LHPs) have received considerable attentions. For LHP operation, the heat is transferred by evaporation of working fluid in the evaporator and condensation in the condenser. The working fluid is circulated by the capillary force developed in the porous media [5,6]. No excess power consumption is needed for the operation. In ground-based thermal management as well as in space application, the LHP is considered as a potential mean for heat dissipation. However, with the miniaturization of the flat LHP, the heat transport distance and the heat load that the loop can transfer sharply decrease. For the copper and water, acetone, methanol combinations, the transport distances of the loops presented in the literatures are all lower than 500 mm [7–13]. On the occasion of long heat transport distance, this type of loop cannot meet the demand. Moreover, in a certain heat load range of LHP operation, temperature oscillation is found on the evaporator surface. The oscillation would cause the thermal stress on surfaces such as the silicon chips, resulting in functional decrease and structure failure. The temperature oscillation is appeared due to the liquid–vapor interface fluctuation inside the compensation chamber, which is induced by the heat leak from the evaporator to the compensation chamber

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http://dx.doi.org/10.1016/j.applthermaleng.2015.08.076
1359-4311/

Nomenclature

Q	heat load, W
P	pumping power, W
T	temperature, °C
V	volume, ml

Greek symbols

α	liquid charging ratio
γ	the percentage of vapor in condenser #1

Subscripts

sink	heat sink
loop_ex	the loop except reservoir
res	reservoir
vap_l	vapor line
vap_cham	vapor chamber
cond_#1	condenser #1

Abbreviations

CC-out	compensation chamber outlet, T6
CC-in	compensation chamber inlet, T18
Wall	heater surface, T1–T4
Amb	ambient
Cond-#1-in	condenser #1 inlet, T9
Cond-#2-in	condenser #2 inlet, T10
Evap-out	evaporator outlet, T5

[14–18]. In order to solve the drawbacks of the LHP system, the pump-assisted capillary phase change loop is carried out.

The pump-assisted capillary phase change loop is composed of an evaporator, a mechanical pump, a reservoir, an ejector, a condenser, liquid line and vapor line. The schematic of the loop is shown in Fig. 1. The evaporator is a core component for absorbing waste heat from electronic devices. The liquid forced by the mechanical pump is divided into two branches in the evaporator. Most of the liquid directly passes through the compensation chamber. Owing to the effect of the forced-convection heat transfer process in the compensation chamber, the heat leak from the evaporator to the compensation chamber is removed. Meanwhile, a small amount of liquid collects in the porous wick for wick boiling. The new evaporator design provides a more robust solution by adding a bypass line on the compensation chamber. This bypass line removes the excess liquid from the evaporator, ensures the stable thin film boiling, and eliminates the fluctuation of the liquid–vapor interface inside the compensation chamber. The condenser in the loop provides an overcapacity, not only for condensing the vapor phase but also for providing a few degrees of sub-cooling. After the working fluid is condensed, the ejector helps join the sub-cooled liquid together to the reservoir. For the operational safety of the mechanical pump, the reservoir includes extra liquid in the loop and supplies of pure liquid at the pump inlet. During the operation, the mechanical pump continuously supplies the liquid for cycling in the liquid circuit.

The presented pump-assisted capillary loop is a combination of the active and passive systems. Specifically, the mechanical pump in the loop guarantees the liquid circulation in the liquid circuit to achieve a long transport distance, while the system mainly uses thin film boiling to transfer heat. With the assistance of the mechanical pump, the heat transport distance of the pump-assisted capillary phase change loop has a great increase. At the same time, both the latent heat and the sensible heat of the working fluid are utilized to remove the waste heat load. In this way, a small liquid flow rate is required for dissipating a large heat power. In contrast to an active two-phase cooling loop such as a two-phase micro-channel system, in which two-phase mixed flow occurs during flow boiling and which leads to a large pressure drop and corresponding high power consumption of the pump, the vapor phase and liquid phase in the presently considered loop are passively separated into different lines by the capillary force.

In the past few years, researchers have experimentally investigated the pump-assisted capillary phase change loop [4,19–22]. In spite of the different design of the loops, the various loops all aimed to solve the problems of the limited heat transport distance and low heat load. Park et al. [4,23–25] performed a series of experimental tests on the pump-assisted capillary two-phase loop. It was concluded that, the evaporator was flooded or was generating enough vapor could be determined by looking at the thermal resistance in the system. Meanwhile, the dual-evaporator structures with a series arrangement and parallel arrangement were tested and discussed in terms of their operational characteristics and limitations [24]. Schweizer et al. [19] fabricated a simplified mechanically pumped two-phase loop and examined its steady-

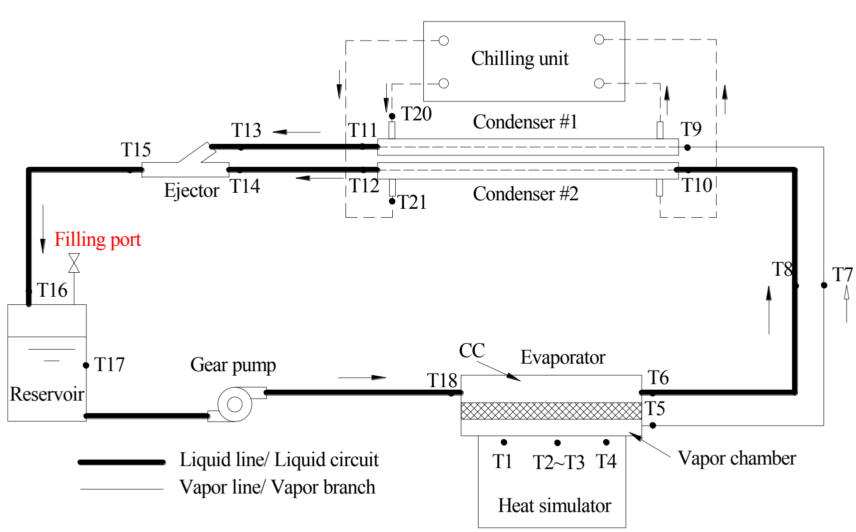

Fig. 1. Schematic of pump-assisted capillary phase change loop.