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Research Paper

Startup characteristics of pump-assisted capillary phase change loop

Chi Jiang, Wei Liu *, Zhichun Liu, Jinguo Yang, Bin Duan, Xiaobing Luo

School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China

HIGHLIGHTS

- A self-designed impeller pump was used in the pump-assisted capillary loop.
- The pre-conditions on the startup characteristics were classified and analyzed.
- The pump-assisted capillary loop was validated to handle well with bubble generated in CC.

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ABSTRACT

In this study, startup characteristics of a pump-assisted capillary phase change loop under various operational conditions were experimentally investigated. For the loop fabrication, a self-designed impeller pump was selected to reduce the volume and weight of the loop. Methanol was chosen as the working fluid. The test results indicated that the pre-conditions in the evaporator had a large impact on the startup characteristics. When the vapor chamber was occupied, partially or completely, with liquid before startup, a temperature overshoot appeared in the heater wall temperature profile. As a higher heat load was applied to the evaporator, vapor bubbles generated in the compensation chamber. Under these conditions, the loop still operated steadily, and the heat transfer capability of the evaporator improved. To avoid the boiling conditions that appeared in the compensation chamber, either lowering the heat sink temperature or increasing the pumping power was the effective manner.

1. Introduction

As the heat flux of electronic components gradually increases, a highly efficient cooling system is required. Among the numerous cooling technologies, heat transfer via phase change of the working fluid is considered as an efficient method. Previously, the capillary-driven loops, such as capillary pumped loops (CPLs) and loop heat pipes (LHPs), which served as a typical two-phase loop, were used to dissipate the high heat flux [1–5]. The operation of the loops relies on the capillary force generated in the evaporator without external power consumption [6–9]. Meanwhile, based on the shape of the evaporator, LHPs can be divided into the two types: cylindrical and flat-plate. In contrast to the cylindrical evaporator, the flat-type evaporator directly contacts the heater surface, which vastly decreases the thermal resistance between the heater wall and the evaporator. The flat-type LHP possesses a high heat transfer efficiency. However, as the miniaturization of the flat-type LHP, the capillary pressure head the evaporator developed decreases, which restricts the loop performance, such as the effective length of the loop and the maximum heat load applied to the evaporator [10–12]. Moreover, owing to the structure of the flat evaporator, the heat is likely to leak from the evaporator to the compensation chamber, leading to a change in the thermal and hydrodynamic conditions in the compensation chamber. This causes temperature oscillation in LHP [13–15]. Therefore, to overcome the shortcomings in LHP, a pump-assisted capillary phase change loop was proposed [16]. As shown in Fig. 1, pump-assisted capillary phase change loop consisted of an evaporator, a condenser, an ejector, a reservoir, a mechanical pump, and transport lines. During operation of the loop, liquid in the reservoir was forced by the pump through the evaporator. In the evaporator, the liquid was divided into two separated branches. Most of the liquid flowed through the compensation chamber, while only a small amount of liquid passed through the porous wick to vapor chamber. The liquid in the vapor chamber absorbed heat and then evaporated. Subsequently, the generated vapor flowed through the vapor channels to the vapor line and was cooled in condenser #1. Meanwhile, a small quantity of heat, called heat leakage, transferred through the evaporator sidewall to the compensation chamber. The heat leak was removed by the flowing liquid through the compensation chamber. The heated liquid passed through the compensation

* Corresponding author.
E-mail address: w_liu@hust.edu.cn (W. Liu).

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Nomenclature

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

Subscripts

sink	heat sink

Abbreviations

Amb	ambient temperature, °C
CC	compensation chamber
CC-in	compensation chamber inlet temperature, TC15
CC-out	compensation chamber outlet temperature, TC6
Cond-#1-in	condenser #1 inlet temperature, TC8
Cond-#2-in	condenser #2 inlet temperature, TC7
Evap-out	evaporator outlet temperature, TC5
wall	heater wall temperature, average of TC1-TC4

chamber outlet and reached condenser #2. In the condenser, vapor and the heated liquid released heat and transformed to the subcooled state. The subcooled liquid at the condenser outlets was combined in the ejector and then forced back to the reservoir. With the assistance of the pump, the liquid began to circulate for the next circle. Based on the running process of the pump-assisted capillary phase change loop, the liquid transmission capability increased by adding a pump in the loop. The loop could meet the requirement of transport distance by properly adjusting the power consumption of the pump. Meanwhile, in the evaporator, latent heat of the working fluid was used to dissipate heat. For the same heat flux, utilizing phase change required less circulating working fluid than the single-phase loop. As a combination of active cooling and passive cooling loop, pump-assisted capillary phase change loop possessed high heat transfer capability, long transport distance, and strong operational stabilization.

Until recently, a number of experimental investigations on pump-assisted capillary loop have been performed. Specifically, Park et al. [17–19] performed a series of experiments on pump-assisted capillary phase change loop. In the experimental study, the effect of external conditions on the operational characteristics of the loop was tested in detail. The results indicated that the loop had the potential to dissipate high heat flux. No obvious temperature oscillation was found throughout the loop. Babin et al. [20] proposed an analytical model to predict the performance of the pump-assisted capillary loop. The results of the analytical model revealed an increase in performance ranging from 20% to 100% owing to the addition of an ion-drag pump. Simultaneously, an experimental loop was developed to verify the accuracy of the analytical model. Schweizer et al. [21] designed a mechanically pumped two-phase loop by inserting an annular gear pump into the liquid line to provide the mechanical pumping force. The test results showed that the loop worked adequately in all orientations. Hoang et al. [22] proposed a mechanical/capillary hybrid pump loop and selected the ABI bearingless pump as the mechanical pumping force. A three-month performance test was performed on the test loop to establish the operational characteristics. The test results indicated that the loop could run smoothly during the entire operating periods. The loop in this study was quite different from other studies. In Park's loop [17–19], the evaporator contained a complex structure and was coupled with the heater block. This was not practical for cooling an actual electronic device. Meanwhile, the reservoir not only contained the excess liquid in the loop but also played a role to cool the vapor from the vapor line. This created a complex loop structure and was not suitable for a compact design of the loop. In Babin's work [20], only the prototype of the loop was proposed. The author chose the ion-drag pump to provide the pumping force, which led to a complex pump control system. Moreover, for selection of the working fluid, the polarity of the working fluid should be considered, which would restrict the selection range of the working fluid. For the loop presented by Schweizer [21], no excess liquid outlet was designed on the compensation chamber. Therefore, the pumping liquid would entirely pass through the porous wick. This would lead to an increase of flow resistance of the loop. In addition, the generated vapor in the vapor chamber would be eliminated by the pumping liquid, and then, the evaporator would operate with low heat transfer efficiency. In Hoang's work [22], the cylindrical evaporator increased the thermal contact resistance. This led to the degradation of the evaporator performance. In this study, efforts were made to improve the loop performance. To decrease the evaporator size and the thermal contact resistance, the evaporator was designed in flat type, which could easily contact the heat source. To reduce the flow resistance of loop, excess liquid outlet was designed on the compensation chamber. Meanwhile, the placement of the porous wick in the evaporator effectively sepa-

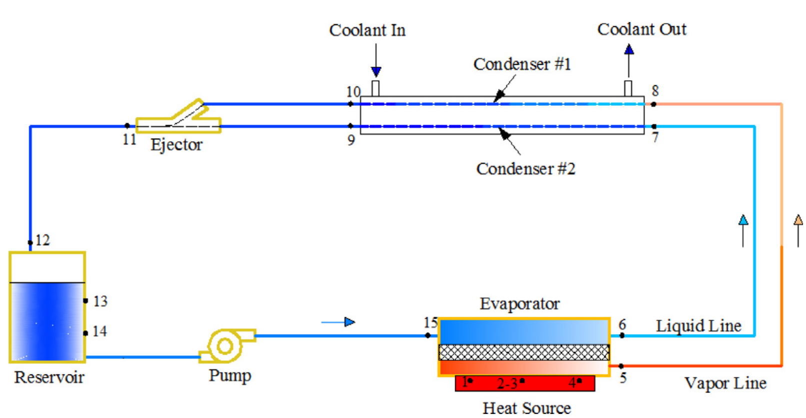

Fig. 1. Schematic of the pump-assisted capillary loop and the main test points throughout the loop.