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Experimental research about the boiling heat transfer mechanism in a pump driven loop thermosyphon system

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ABSTRACT

This work has studied the boiling heat transfer mechanism in a pump driven loop thermosyphon system. The coolant is Freon R134a which flows and boils in a tube with inside diameter of 8.05 mm. The results show that at a constant heat flux, the boiling heat transfer coefficient is not influenced by the coolant's mass flow rate. In other ward, the boiling mechanism at this situation is the nucleate boiling instead of the convection boiling.

Keywords: Boiling mechanism, Nucleate boiling, Pump driven, loop thermosyphon

NONMENCLATURE

Abbreviations	
Q	Heat transfer rate (W)
T	Temperature (°C)
KA	The heat transfer coefficient of the evaporator (W/K)

1. INTRODUCTION

Loop thermosyphon is a kind of heat transfer equipment with high heat transfer ability which can be used widely in many industrial areas like data center cooling [1], waste heat recovery [2] and etc. As has known to all, the loop thermosyphon is driven by gravity without any pump [3].

However, in some special condition, a coolant pump is necessary to be added into the loop thermosyphon system. For example, if the resistance force is higher than the driven force, the coolant cannot flow normally (for example, blockage happen). At this time, the heat transfer condition will become worse and the loop thermosyphon even cannot start normally. In order to solve this problem, a pump should be equipped into the system to increase the driven force. A loop thermosyphon with a pump equipped is called the pump driven loop thermosyphon system.

In fact, it is obviously that adding a pump can increase the driven force of the coolant and also increase the mass flow rate of the coolant. However, it is an important topic to study the pump's influence on heat transfer character.

There are mainly two kinds of view about the heat transfer mechanism [4-9] in the flow boiling process inside a tube. Some researchers think that the boiling heat transfer coefficient is mainly influenced by the heat flux but has nothing to do with the coolant's mass flow rate [4, 5, 6, 7], and such mechanism is called the nucleate boiling. But some other researchers trust that the boiling heat transfer coefficient is not only enhanced by heat flux but also by mass flow rate, and such mechanism is called the convention boiling [8, 9].

In this work, the pump driven flow boiling mechanism inside the tube has been studied by experiment method, and the experiment results will be introduced in the following parts.

2. EXPERIMENT SETUP

The experiment system has been made up of mainly three cycles. Including the heating water cycle, the cooling water cycle and the loop thermosyphon cycle. There is a Coriolis mass flow rate meter equipped in the liquid pipe to measure the coolant's mass flow rate. The pressure sensors are placed at the inlet and outlet points of the evaporator to measure the operation pressure of the thermosyphon and the saturation temperature can be calculated by the operation pressure. The coolant is driven by a pump which is installed inside the thermosyphon. During the experiment process, the Freon R134a is used as the coolant.

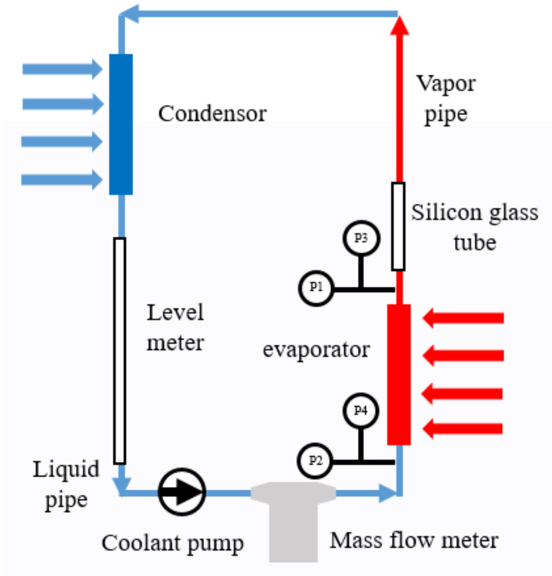

Figure 1 The scheme of the loop thermosyphon system, not in scale

In this system, as the heat source is hot water, the heat transfer rate can be calculated by equation (1). Here, the T_{hi} and T_{ho} mean the hot water's inlet and outlet temperature. The total heat transfer coefficient can be calculated by equation (2). Here, T_e means the evaporation temperature and Q is the heat transfer rate in equation (1).

$$Q = c_p m(T_{ho} - T_{hi}) \quad (1)$$

$$KA = \frac{Q}{(T_{hi} + T_{ho})/2 - T_e} \quad (2)$$

It should be noted that the KA is the total heat transfer coefficient of the evaporator which is calculated by Newton's cooling law (see equation 2).

3. EXPERIMENT RESULT

3.1 The relationship between mass flow rate and heat transfer coefficient

In order to analysis the relationship between mass flow rate and boiling heat transfer coefficient, we let the hot water's inlet temperature be constant, and change the frequency of the coolant pump.

During the experiment, the hot water's mass flow rate is about 192.6 kg/h, as the hot water's temperature and mass flow rate are both constant, the hot water side's convection heat transfer coefficient is also constant in figure 2. Thus, as long as the total KA of the evaporator is constant, the boiling heat transfer coefficient of R134a coolant also remains constant.

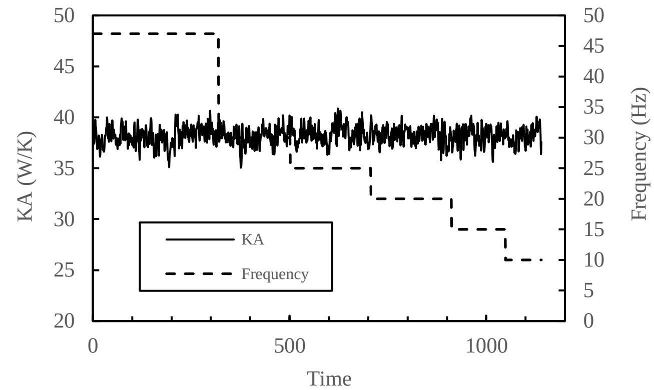

Figure 2 The variation trend of evaporator's KA and pump's frequency over time, the heat flux is about 376 W

In fact, as the experiment results show, although the pump's frequency changes quite a lot, the KA of the evaporator almost remains constant.

Table 1 has listed the relationship between the pump's frequency and the coolant's mass flow rate. As can be seen from the table, during the experiment process of the figure 2, the coolant mass flow rate variates from about 219-87 kg/h.

Table 1 The pump's frequency and coolant's mass flow rate

Frequency (Hz)	47	30	25	20	15	10
Mass flow rate (kg/h)	219	182	164	145	118	87

3.2 The analysis of the stability

In order to find whether the heat transfer coefficient can be influenced by the mass flow rate, it is important to analyses the stability of the parameters during the experiment process.

In figure 3, the variation trends of the saturation temperature (calculated by saturation pressure), the inlet and outlet temperature of the hot water over time have been listed.

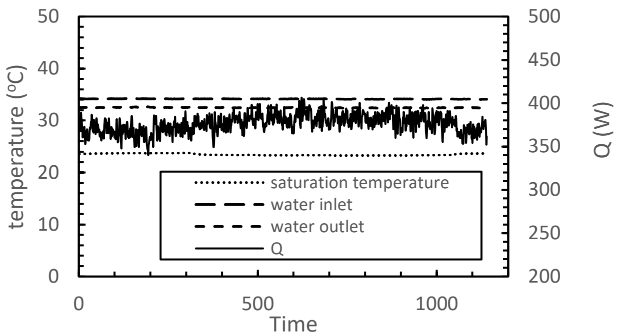

Figure 3 The variation trend of the temperature and Q over time

In figure 2 and 3, the sample's interval is 5 second, as there are 1140 points in figure 2 and 3, the total experiment time is about 95 minutes. It can be seen that with time goes by, the 3 temperatures almost remain constant, thus, the heat transfer ability also remains almost constant.

Based on the experiment results, the KA of the evaporator is 38.2 $\pm$ 0.89 W/K, the heat transfer ability is 376 $\pm$ 10 W (here, the 0.89 W/k and 10 W means the standard deviation). It can be seen that the variation range is about 2-3% for both KA and Q, however, the variation trend for R134a's mass flow rate is about 250%, as is calculated by the results in table 1.

Based on the above analysis, we can draw the conclusion that although the mass flow rate changes quite a lot, the heat transfer coefficient has nothing to do with such changes. The boiling heat transfer coefficient is mainly influenced by heat flux and the coolant's mass flow rate almost do not influence the boiling heat transfer coefficient.

3.3 The relationship between the mass flow rate and the evaporator's pressure difference

In fact, it is important to know the relationship between the coolant's mass flow rate and the evaporator's pressure difference (DP).

As can be seen in figure 1, there are two pressure sensors at the inlet (or outlet) point of the evaporator. The pressure difference of the evaporator can be calculated by $DP=|P_2-P_1|$. In fact, the max measurement results of these two pressure sensors P1 and P2 is about 0.00058 MPa when measure the same pressure. Compared with the pressure difference of the evaporator, which is about 0.0126-0.0208 MPa, such 0.00058 MPa is too little to be omitted.

Figure 4 shows the relationship between the pressure difference and the coolant's mass flow rate. The figure 4 is obtained from the data in figure 2 and 3, the results in this figure is the average results. It has been found that after changing the frequency of the coolant pump, the mass flow rate will also variate quickly, thus the variation process is also obtained in the average results.

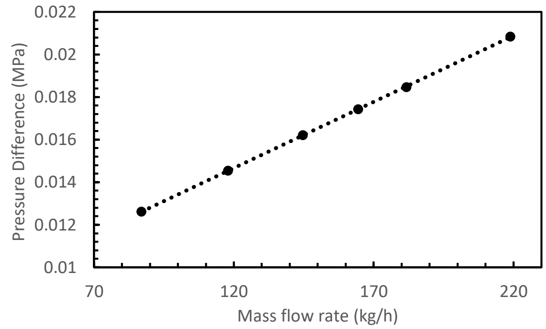

Figure 4 The relationship between the coolant's mass flow rate and the pressure difference of the evaporator

As can be seen form the figure 4, the DP increases with the increasing of the mass flow rate, these two parameters shows good linear relationship.

3.4 The uncertainty analysis

As for the measurement error by instruments, the coolant's mass flow rate is measured by Coriolis mass flow rate with accuracy of 0.5%, the pressure is measured by pressure sensor with accuracy of 0.2% (the calibration results show that the real error is much lower than such results, it is about 0.0021 MPa between the measurement result and the real pressure), the temperature is calculated by thermal couple whose accuracy is 0.1 °C after calibrated. It should be also noted that, on measuring the same pressure, the max difference between pressure sensors P1 and P2 is only 0.00058 MPa. Thus, it is accurate to measure the pressure difference by only two pressure sensors.

As for the system error, since the experiment system is now under testing and has the problem of little leakage. However, as the coolant's liquid level height of the system almost does not decrease before and after the experiment, we think such leakage is too little to be omitted during the experiment.

4. CONCLUSION

a) At a constant heat source temperature, the coolant's mass flow rate changes 250% while the heat transfer rate and KA of the evaporator almost remain constant, the variation trend is only about 2-3%.

b) At a given heat flux, the boiling heat transfer coefficient has nothing to do with the coolant's mass flow rate.

c) For the pump driven upward flow boiling process, the mechanism is nucleate boiling instead of the convention boiling.

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REFERENCE

[1] Ding T, He Z G, Hao T, Li Z. Application of separated heat pipe system in data center cooling. Appl Therm Eng. 2016; 109: 207–16.

[2] He Z, Ding T, Liu Y, et al. Analysis of a district heating system using waste heat in a distributed cooling data center. Appl Therm Eng. 2018; 141: 1131-1140.

[3] Li Z, Kandlikar SG. Current status and future trends in data-center cooling technologies. Heat Transf Eng. 2015; 36(6):523–38.

[4] Oh HK, Son CH. Flow boiling heat transfer and pressure drop characteristics of CO 2 in horizontal tube of 4.57-mm inner diameter. Appl Therm Eng. 2011; 31(2–3):163–172.

[5] Choi K Il, Pamitran AS, Oh JT. Two-phase flow heat transfer of CO2 vaporization in smooth horizontal minichannels. Int J Refrig. 2007; 30(5):767–777.

[6] Basu S, Ndao S, Michna GJ, Peles Y, Jensen MK. Flow boiling of R134a in circular microtubes - Part I: Study of heat transfer characteristics. J Heat Transfer. 2011; 133(5).

[7] Tao Ding, Hanwen Cao, Zhiguang He, Zhen Li. Experimental investigations of the influence factors for the boiling heat transfer characteristics of R134a coolant in a loop thermosiphon system. Int J Refrig. 2020, 115:182-190.

[8] Aroonrat K, Wongwises S. Evaporation heat transfer and friction characteristics of R-134a flowing downward in a vertical corrugated tube. Exp Therm Fluid Sci. 2011; 35(1):20–28.

[9] Aria H, Akhavan-Behabadi MA, Shemirani FM. Experimental investigation on flow boiling heat transfer and pressure drop of HFC-134a inside a vertical helically coiled tube. Heat Transf Eng. 2012; 33(2):79–87.