Experimental Investigation on Heat Transfer Performance of A Cryogenic Thermosyphon

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As a high performance heat transfer device, the thermosyphon has many promising applications in cryogenic technique and superconductive magnet cooling. In this paper, the thermosyphon made of stainless steel has an operating length of 6.0×10^{-1} m and an inner diameter of 0.9×10^{-2} m. The effects of the filling ratio and inclination angle on its heat transfer rate are experimentally investigated. For this self-made thermosyphon, the optimum filling ratio is about 18.5% and the optimum inclination angle to the horizon is about 50^{o}.

INTRODUCTION

With advancements in cryocooler-based applications such as cryocooler-cooled superconducting magnets, it will be required to search for effective means of heat transfer between components to be cooled and cryocoolers. At present, the most common means of heat transfer in these applications is heat conduction by copper bar. But in dealing with many applications, where the heat transfer distance would be large, this method will impose a limit on the heat transfer by its cross-sectional area available for heat conduction. To alleviate this constraint on the heat transfer by the conduction bar cross-section, one would need to look for heat transfer means that can transfer much more heat for the same temperature difference.

As an attractive alternative, heat pipes are known to be effective in such heat transfer. The cryogenic heat pipe (working temperature is from 0 to 150 K) reported in the literature can be categorized into four groups[1]: thermosyphon, wick-based heat pipe, cryogenic capillary-pumped loop and cryogenic loop heat pipe. The thermosyphon is a gravity assisted wickless heat pipe which has been utilized for cooling electrical devices, extracting a thermal energy from solar heat or geothermal heat sources. It is a practical heat transfer device due to its simple structure and low production cost. Here, we focused on a cryogenic two-phase nitrogen thermosyphon. It is important to grasp the effects of filling ratio and inclination angle on the heat transfer rate of thermosyphon. In this study, the effects of both filling ratio and inclination angle on heat transfer characteristics are experimentally investigated.

EXPERIMENTAL SET-UP

The schematic illustration of the experimental apparatus is shown in Figure 1. It consists of a thermosyphon, a cryostat, a liquid nitrogen container, an evacuation device for evacuating the inside of the thermosyphon and the cryostat, and a reservoir tank for measuring the amount of charged gas[2]. The thermosyphon made of stainless steel (1Cr18Ni9Ti) has an operating length of 6×10^{-1} m, an inner diameter of 0.9×10^{-2}m and a tube wall thickness of 0.1×10^{-2} m. The evaporator section is electrically heated. The condenser section is cooled by liquid nitrogen in a liquid nitrogen container.

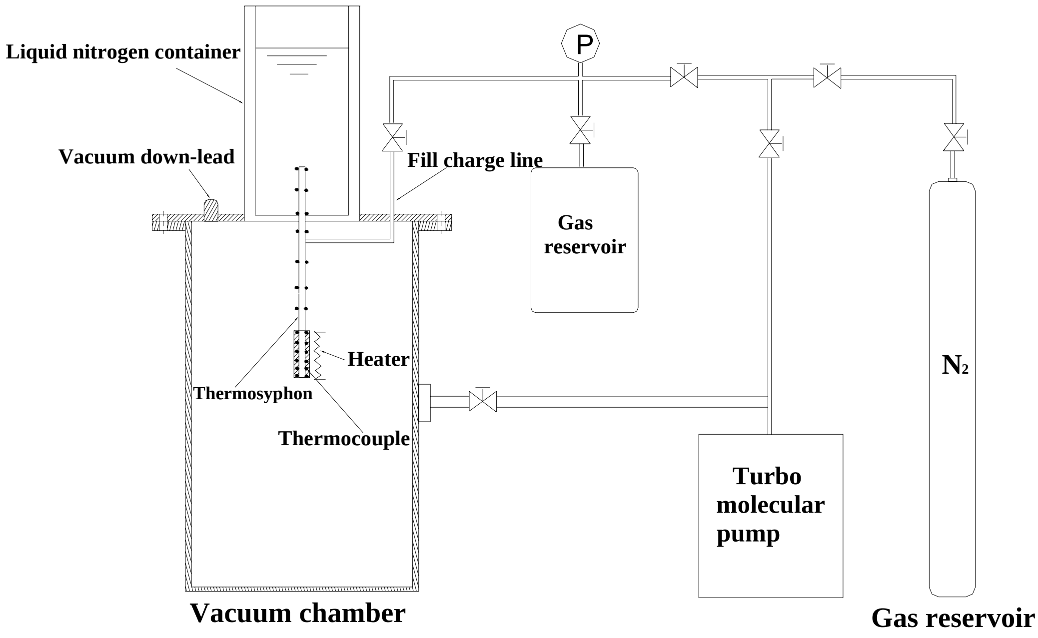


Figure 1 Schematic illustration of the experimental set-up

The thermosyphon is divided into the evaporator section, the adiabatic section and the condenser section. Through changing the length of evaporator section, two cases are experimentally investigated. The lengths of the three parts are shown in Table 1, respectively.

Table 1: Length of thermosyphon

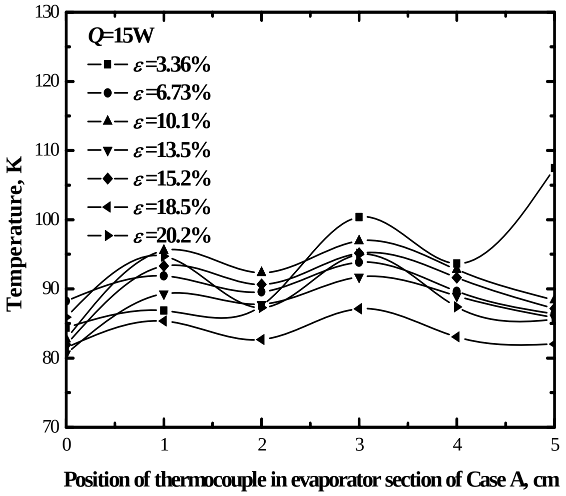
	Case A	Case B
L_e (cm)	5	10
L_a (cm)	45	40
L_c (cm)	10	10

After sufficiently evacuating the inside of the thermosyphon, the gaseous nitrogen is charged into the thermosyphon through the fill charge line from the gas reservoir. The gaseous nitrogen is condensed into liquid on the cooled condenser wall. Then, the liquid flows down to the evaporator section and forms a pool. The amount of the liquid nitrogen fill charge is calculated from measuring the pressure difference of pre and post liquefaction in the reservoir tank. The filling ratio ε is defined as the volume ratio of charged liquid nitrogen to the whole volume of the thermosyphon.

In this experiment, temperatures of the outer surface of evaporator section are measured by the copper-constantan thermocouples (see Figure 1). The temperatures are acquired by the Keithley2700 type multimeter, which starts as soon as the thermosyphon works.

RESULTS AND DISCUSSION

The temperature measurements are carried out in two cases as mentioned above. And the latter analysis, the heating power Q is fixed. In each case, the temperature in evaporator section changes drastically along with the position, and the change trend of temperature is the same despite of the filling ratio ε as shown in Fig. 2 and Fig.3. The temperatures of the condenser section are fixed during a series of measurements. The temperatures at the evaporator section are the average values of the output from the two thermocouples on both sides, as shown in Fig. 1.



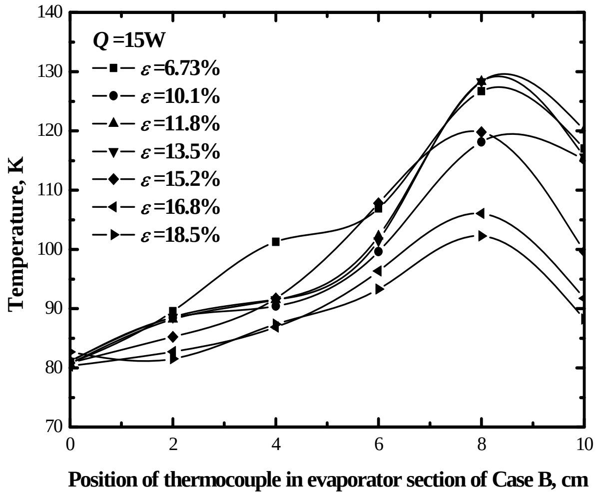


Figure 2 Optimum filling ratio of Case A

Figure 3 Optimum filling ratio of Case B

Fig. 2 shows the typical results of the steady temperature distribution along the axis of the evaporator with various values of filling ratio in the case A. For the given thermosyphon in this paper, when ε =18.5%, the mean temperature in the evaporator section is minimum as shown in Fig. 2. The lower this mean temperature, the better the cooling effect. So an optimum filling ratio of this thermosyphon exists, and should be in the range of 15% to 20%. This is because, less filling mass will result in the liquid working fluid drying off, whereas much filling mass will result in the liquid working fluid boiling when the thermal resistance of vapor film in liquid pool of evaporator section should be considered. It should be noted that the working fluid of thermosyphon is in the supercritical state at ambient temperature, excessive working fluid will be dangerous too.

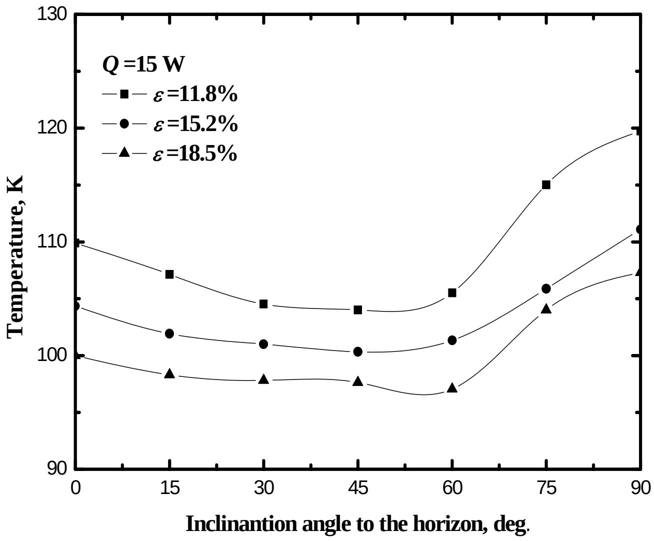


Figure 4 Effects of inclination angle in Case B

Fig. 3 shows the typical results of the steady temperature distribution along the axis of the evaporator for various values of filling ratio in the case B. The mean temperature with a certain filling ratio in this case is higher than that in case A correspondingly. This is because, the length of evaporator section in case A is shorter than that in case B, where the working fluid condensed is not enough to give a rapid supply to the evaporator section, which will result in the temperature of the evaporator section rising.

In the ground applications, the condensate on the inner surface of the condenser section flows down to the evaporator section at a certain speed, which results from the gravity. The speed is varied with the inclination angle of thermosyphon. To study the effect of inclination angle to the horizon on the heat transfer rate, the inclination angle is varied from 0 to 90^{o} as shown in Fig. 4. The temperatures in this figure are the average values of the whole evaporator section. Similar to our earlier shown results, for any given inclination angle, the optimum filling ratio is always 18.5%, because the mean temperature of the whole evaporator section is the lowest. And for a chosen filling ratio, with an initial increase in the inclination angle, the mean temperature decreases, which effects high heat transfer rate; but beyond a certain value of about 50^{o}, the mean temperature increases, which results in decreasing heat transfer rate. So there exists an optimum inclination angle too.

CONCLUSIONS

In this study, with regard to the filling ratio and inclination angle, the heat transfer rate of a self-made cryogenic thermosyphon is experimental investigated in terms of mean temperature in the evaporator section. The following conclusions are obtained:

1. There exists an optimum filling ratio for any thermosyphon. Too much or too little filling mass will result in bad effects on the heat transfer rate of a thermosyphon. For this self-made thermosyphon, the optimum filling ratio is about 18.5%.
2. The inclination angle also has strong effect on the heat transfer rate of a thermosyphon in the ground application. For this self-made thermosyphon, the optimum inclination angle is about 50^{o}.

ACKNOWLEDGEMENTS

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