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Evaluation of liquid behavior in a Variable Conductance Heat Pipe by neutron radiography

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ABSTRACT

A Variable Conductance Heat Pipe (VCHP) is used as a cooling device for electrical equipments. The condensation area is passively controlled by the non-condensable gas volume in the VCHP depending on the heat load. The VCHP has often a bent pipe between the evaporation and condensation area. The heat pipe performance depends much on the bent pipe shape and configuration because a liquid plug is formed in the bent pipe and disturbs the refrigerant circulation. However, the mechanism has not been clarified well. The neutron radiography system at the JRR-3 in Japan Atomic Energy Agency (JAEA) was used to visualize the refrigerant behavior in the VCHP. Effects of the thin plate inserted in the pipe, refrigerant filling ratios and heat pipe configuration were examined on the heat pipe performance. The liquid plug was formed at the bend and caused to decrease the performance. It was confirmed that the thin plate insert was effective to disturb the liquid plug formation.

1. Introduction

Heat pipes are often used as cooling devices for electrical equipments without a moving part. Refrigerant is charged into a metallic pipe and heat is removed by the refrigerant circulation with evaporation and condensation. The refrigerant with small amount of non-condensable gas was also charged into in a Variable Conductance Heat Pipe (VCHP). The condensation area is passively controlled by the non-condensable gas volume in the VCHP depending on the heat load.

The VCHP has often a bent pipe between the evaporation and condensation area, since the condensation section is vertically and the evaporation section is horizontally placed. It has been reported that the heat pipe performance depends much on the bent pipe shape and configuration because a liquid plug is formed in the bent pipe and disturbs the refrigerant circulation. However, the mechanism has not been clarified well.

Neutron radiography had been used for visualization of the refrigerant behavior in the heat pipes [1–3]. Cooling water distributions in a looped heat pipe were clarified [4] and oscillation analysis in a self-oscillation heat pipe was performed [5] using neutron radiography.

In this study, neutron radiography system at the JRR-3 in Japan Atomic Energy Agency (JAEA) was used to visualize the refrigerant behavior in the VCHP. Movies with 30 frames per second were taken by an Electron Bombardment Charged Coupled Device (EB-CCD) camera. Effects of the thin plate inserted in the pipe, refrigerant filling ratio and heat pipe configuration were examined on the heat pipe performance.

2. Experimental apparatus

Schematic diagrams of an experimental apparatus and a tested VCHP are shown in Fig. 1 and 2, respectively. The VCHP consisted of an inner-grooved copper tube with inner diameter of 5.4 mm and thickness of 0.3 mm. Aluminum flat fins were equipped at the condensation area and the fin pitch was about 1.7 mm. The VCHP had a 90°-bend in the adiabatic area between the evaporation and condensation area. It is usually placed as shown in Fig. 2 to make the condensation area vertical. An aluminum heating block with a cartridge heater, which simulated a cooling electrical device, was placed at the top of the evaporation area. Distilled water was charged in the VCHP as the refrigerant with nitrogen gas as the non-condensable gas. A thin plate was inserted as shown in Fig. 2 to disturb the liquid plug formation. Wall temperatures at the evaporation and adiabatic area were measured using K-type sheathed thermo-couples fixed on the tube wall at bottom of the evaporation area and outside of the bend, respectively. Cooling air temperature was also measured by a K-type sheathed thermo-couple inserted at the inlet of the cooling fan.

The configuration of the VCHP could be varied by the rotating system with a stepping motor by an angle of θ. The VCHP was set at an inverted position with $\theta = -135^{\circ}$ and was returned to the

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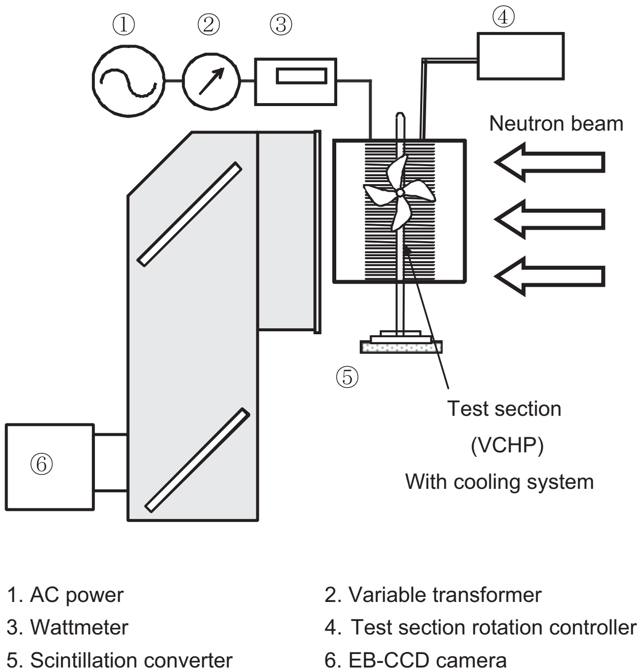

Fig. 1. Schematic diagram of experimental apparatus.

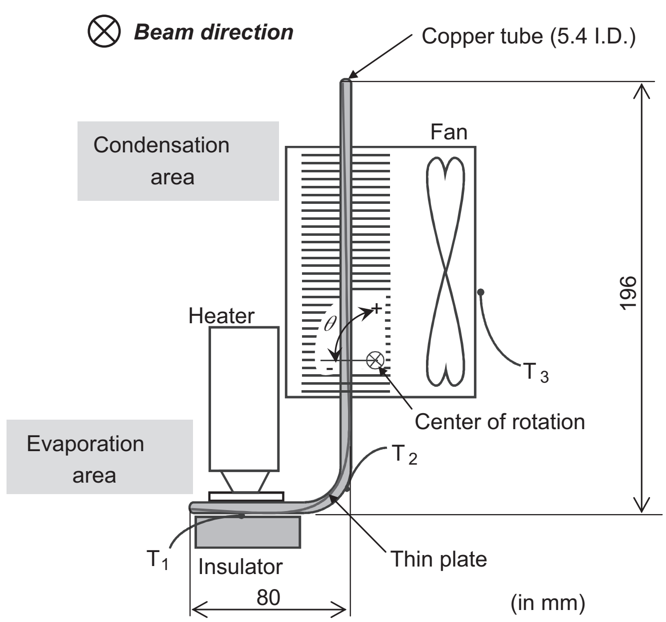

Fig. 2. Test section.

Table 1
Specifications of tested VCHPs.

Type	Amount and volume ratio of filling refrigerant	Thin plate
A	0.39 g, 6.98%	without
B	0.25 g, 4.47%	with
C	0.50 g, 8.94%	with
D	0.98 g, 17.53%	with

standard position with $\theta=0^\circ$ before the operation. Heat input was fixed at 20 W and the cooling air temperature was kept constant at 22 °C. Heating was stopped when the wall temperature at the evaporation area was higher than the practical operation temperature of 50 °C.

Visualization experiments by neutron radiography were carried out using the real-time neutron radiography system at the JRR-3 of JAEA. Video images with 30 frames per second were taken using an EB-CCD camera (C7190-21, Hamamatsu Photonics) with 640×480 pixels in resolution and 8 bit in gray scale. Neutron rays were irradiated perpendicular to the bend in the test section.

Specifications of the tested VCHPs were shown in Table 1. A VCHP without the thin plate (Type A) and three VCHPs with the thin plate in different filling ratio of refrigerant (Types B–D) were tested.

3. Experimental results and discussion

An example of the visualized images of Type C taken by neutron radiography is shown in Fig. 3. The equipments except the heat pipe were covered with B_4C sheets to decrease the radioactivation. The black images of the equipments are masked and only heat pipe images are shown in figures after. The liquid water in the VCHP can be clearly visualized as shown in Fig. 3. The water meniscus can be seen between the wall and the inserted plate in the bend. The water can be also seen at the end of the tube in the evaporation area.

3.1. Effects of a thin plate

The VCHPs are sometimes placed in inverted orientation during installation. The VCHP was set at an inverted position and was returned to the standard position before the operation. Visualized images in Types A and C are shown in Fig. 4(a) and (b), respectively. The images were taken before and after the return to the standard position. In Type A (without the plate), the liquid plug was formed at the bend section as shown in Fig. 4(a). The liquid plug was not broken during the operation and when the wall temperature at the evaporation area was over 50 °C the operation stopped. On the other hand, the liquid plug was not formed in Type C (with the plate) as

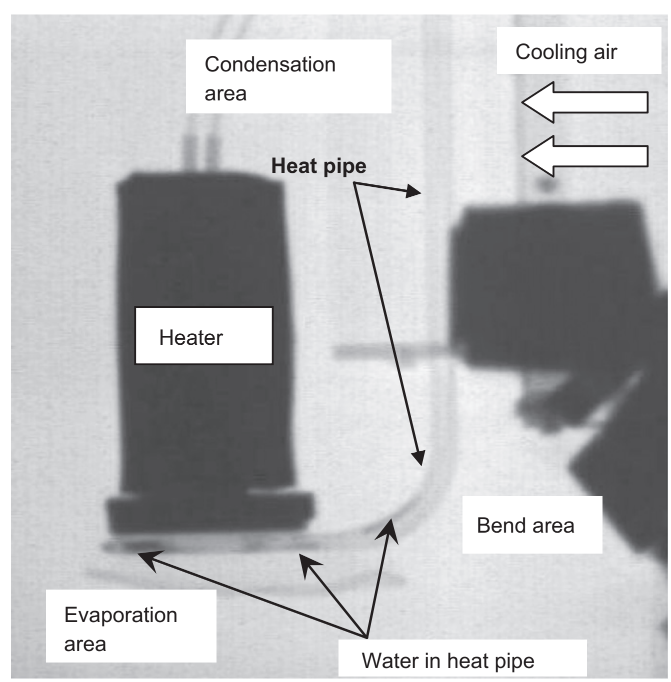

Fig. 3. Example of visualized image of Type C.