An Experimental Investigation of Transient Characteristics in a Gravity-Assisted Heat Pipe

By

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Summary: Transient characteristics of a wickless gravity-assisted heat pipe are investigated experimentally for a rapid temperature change of an evaporator section by submerging in a hot water bath. The results indicate that at high water bath temperature, response time of the heat pipe is kept in a few seconds, but at low temperature it is on the order of minutes and considerable temperature fluctuations are caused by a bumping.

1. INTRODUCTION

A heat pipe has been currently used in many thermal engineering fields due to its highly effective conductivity. In nuclear engineering fields the heat pipe has been used for removal of decay heat from a radioactive waste storage tank [*1*], emergency cooling of gamma ray heat source reactor [*2*], and an irradiation capsule [*3*]. The heat pipe system can maintain high reliability due to its passive cooling system and give an uniform temperature profile with a rapid response. However, in a nuclear reactor a transient rate of temperature and heat flux is much higher than the other thermal devices.

The objective in this study is to obtain understanding of the transient characteristics of a gravity assisted wickless heat pipe. This paper presents experimental results for a rapid change of temperature in an evaporator section of the heat pipe.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

An evaporator section of a heat pipe is quickly submerged in a hot water bath to obtain a rapid transient rate of temperature.

Dimensions of the heat pipe used are shown in Fig. 1. The heat pipe consists of a copper tube with an evaporator, an adiabatic, and a condenser sections. A volume of distilled water charged as a working fluid is 3.4 cm^3 and is equivalent to 94 mm in water level of the pipe. Ten Chromel-Alumel thermocouples, 0.1 mm in diameter, are embedded and soldered on the pipe wall with constant pitch as shown in the figure. Figure 2 shows a schematic diagram of the experimental apparatus. The condenser

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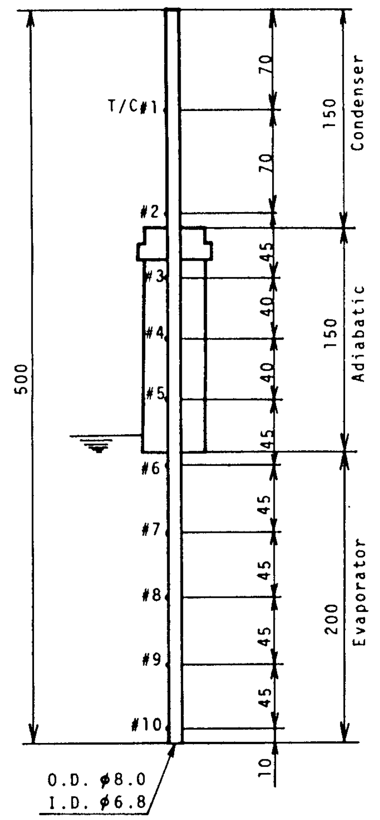

Fig. 1. Dimensions of heat pipe.

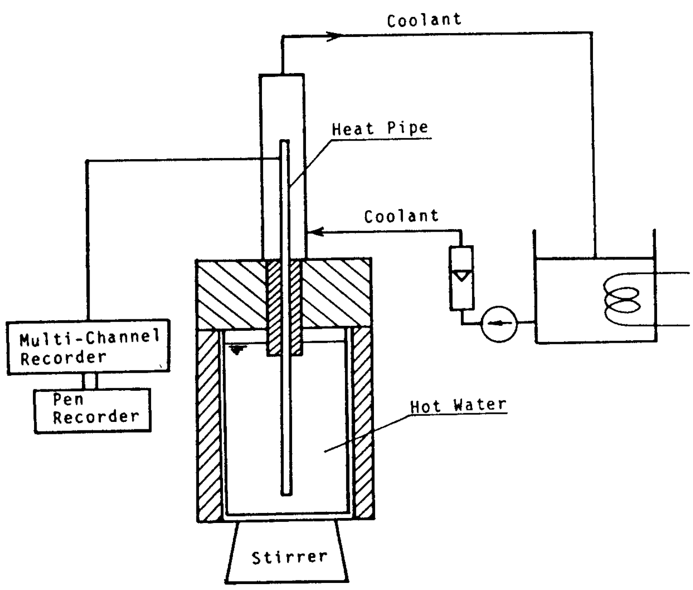

Fig. 2. Schematic diagram of experimental apparatus.

section is cooled by a water coolant flowing with a constant temperature and velocity. The adiabatic section is covered by a glass wool and foamed plastic. The evaporator section is maintained in the air before initiation of an experiment which starts by submerging the pipe in the hot water bath. A temperature of the bath is kept in constant level by a regulation heater and a stirrer. During transient condition, the wall temperatures are recorded on a pen recorder and a multichannel digital recorder. After 60 seconds of heating, the heat pipe is pulled up from the bath. The experiment terminates after temperature measurements of the cooling process.

An operating temperature of water in the bath, T_1, ranges from 65 to 95°C. Three condenser coolant flow rates V of 8, 15, and 25 l/min are chosen. The condenser coolant inlet temperature is kept constant at 25°C. The tests are operated three times at the same initial conditions to examine reproductivity of the tests. Besides transient experiments, steady state experimental data are obtained.

3. Results and Discussions

Three patterns of the temperature transient are observed as shown in Figs. 3, 4, and 5. Those patterns are mainly dependent on the water bath temperature. Figure 3 presents the first pattern observed at high water bath temperature over 90°C. The temperature at the evaporator suddenly decreases in a few seconds after initiation of immersion of the heat pipe, and the temperatures at the adiabatic and the condenser are increasing. This transient behavior might be caused by an inception of nucleate boiling. After the change all the temperatures become stable and constant values nearly equal to the ones given by a steady state experiment, as shown in the figure. After the pipe is pulled out of the bath (about 53 seconds), the temperatures are increasing for a moment and decreasing exponentially. This temperature increase is due to sudden decrease in heat transfer to the working fluid water caused by a termination of nucleate boiling. In the cooling process, temperature of the heat pipe becomes constant after 3 seconds.

The second typical pattern is shown in Fig. 4 presented in case of low water bath temperature below 75°C. Two different responses from the first pattern are shown in the figure. The first temperature response is caused in the evaporator and the second in the adiabatic. The evaporator temperature keeps almost constant and high values after initial temperature increase. It takes tens of seconds for the temperature to decrease according to an inception of nucleate boiling. Further, the temperature at the lowest location (#10) is not decreasing during the transient experiment in the bath, since its local saturation temperature is higher by 4°C than a temperature of the upper part.

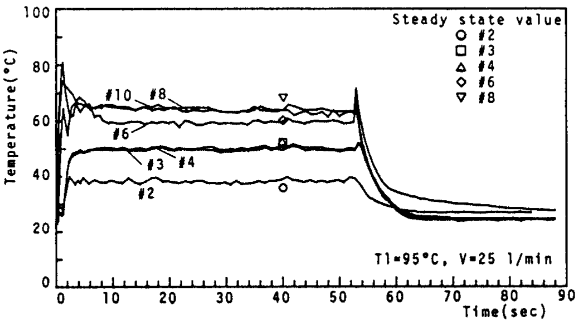

Fig. 3. Transient response at high water bath temperature.

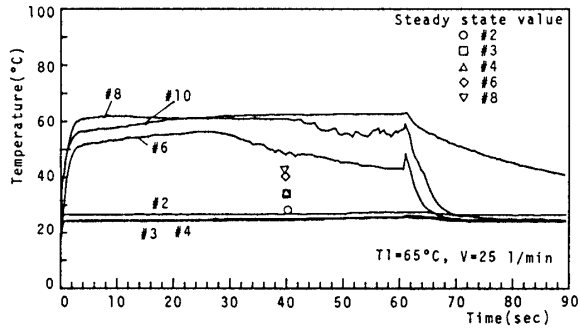

Fig. 4. Transient response at low water bath temperature.

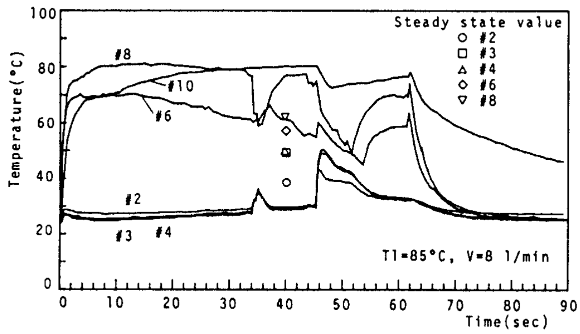

Fig. 5. Transient response at moderate water bath temperature.

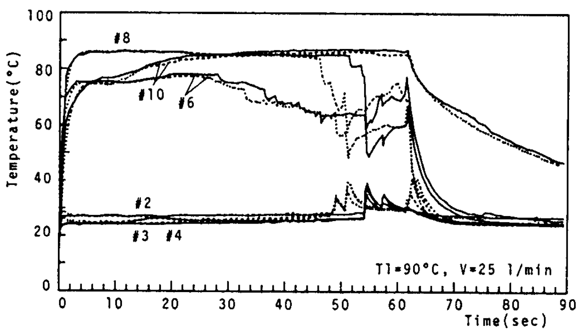

Fig. 6. Reproductivity of experimental data.

The last transient pattern is shown in Fig. 5 observed at the moderate water bath temperature of 85 and 90°C. The temperature shows large temperature drop with intermittent fluctuation. It can be considered that the drop might occur due to a bumping of the working fluid. The bumping makes some amount of liquid carried away to the adiabatic and the condenser sections on account of rapid escape of large bubbles. Therefore, the temperatures of the both sections are appeared to increase suddenly. Whenever this large temperature fluctuation occurs, metallic noise is surely heard from the pipe. In this case, the temperature in the evaporator is still higher than the steady state value.

Two experimental runs with the same test conditions are shown in Figs 6 and 7. The first is represented by solid lines and the second by doted lines. Both lines indicate the

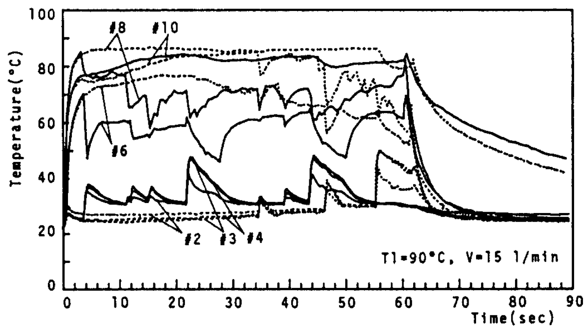

Fig. 7. Reproductivity of experimental data.

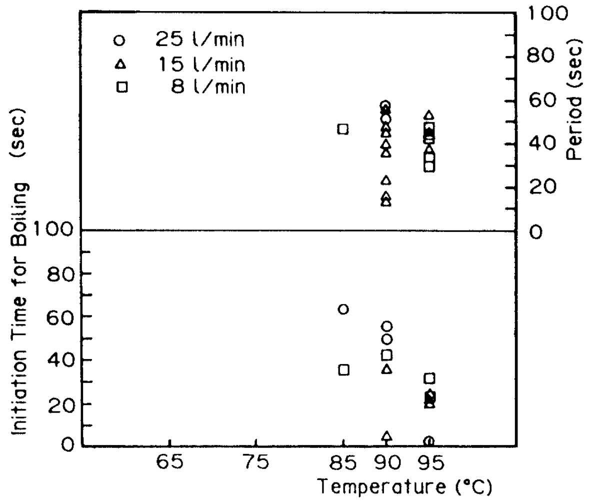

Fig. 8. Initiation time of nucleate boiling and period of temperature fluctuation.

good reproductivity of data until the temperature fluctuation by the bumping occurs.

Figure 8 shows inception time and period of the sudden and large temperature drop by nucleate boiling. It is indicated that the inception time varies inversely as the water bath temperature, independent of coolant flow rate. The periods scatter so much and are independent of the water bath temperature and the coolant flow rate. Derived geysering periods have the same order investigated by Griffith [*4*].

4. Conclusions

Transient experiments of a vertical wickless gravity-assisted heat pipe have been summarized in the followings.

(1) When the temperature of the evaporator section becomes high and cooling ability of the condenser section becomes high enough, the time constant is 3 seconds and the wall temperature can maintain in a stable value.

(2) When the temperature becomes low, the bumping occurs intermittently with large fluctuations of the wall temperature. In this case, transient time is on the order of minutes.

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References

[1] R. H. Davidson, P. G. K. Doroszlai, R. M. Burgoyne, "Transportation and Storage of Spent Nuclear Fuel," Transactions of the ANS Winter Meeting, pp. 183–184 (1981

[2] J. W. Chi, E. C. Philips, "The Development of a Reflux Condensing Heat Pipe For Emergency Cooling of Large Cobalt-60 Heat Source," IAEE-749072, pp. 695–700 (1974)

[3] N. Tsuyuzaki, et al., "Heat-Removal Heat Pipe System of Nuclear Irradiation Facilities," Proceedings of 6th International Heat Pipe Conference, pp. 598–600, Grenoble, France (1987)

[4] P. Griffith, "Geysering in Liquid-Filled Lines," ASME Paper No. 62-Ht-39 (1962)