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Experimental Investigations of Vertical and Horizontal Heat Pipes

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1. Introduction

The interest in the application of heat pipes for heat transfer system is well known in industrial fields. Many researches have presented the conceptual design of heat removal systems using heat pipe to apply nuclear safety systems. Wang et al. [1] and Jouhara et al. [2] referred to the potential of heat pipe technology in nuclear fields, especially for seawater desalination. But this research had the limitation such as high cost and large space for operation. Mochizuki et al. [3] considered making extra inlet devices for in-core cooling using the loop heat pipe but it has a high potential risk of inlet boundary failure. Wang et al. [4] proposed sodium heat pipe system, applied in passive residual heat removal system (PRHRS) of molten salt reactor (MSR). A preliminary concept of PRHRS of MSR using sodium heat pipes was proposed.

Heat pipe uses the working fluid in containment as cylindrical shape tube. Vaporization occurs in evaporation section due to the heat input and vapor is transferred to condensation section. At the condensation area, the working fluid is condensed and immersed in the wick structure, which has highly porous media. The condensed working fluid returns to evaporator section by capillary wicking of wick structure. The driving force for working fluid is affected by capillary and gravitational force. The heat pipes for nuclear systems have been suggested as horizontal loop heat pipes for reactor core cooling system or vertical heat pipes for passive cooling for spent fuel.

In the present research, preliminary tests of horizontal and vertical heat pipe were studied for its heat transfer performance.

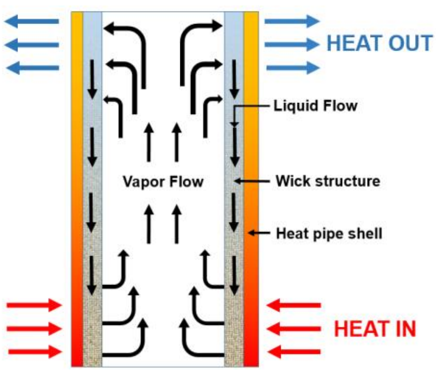
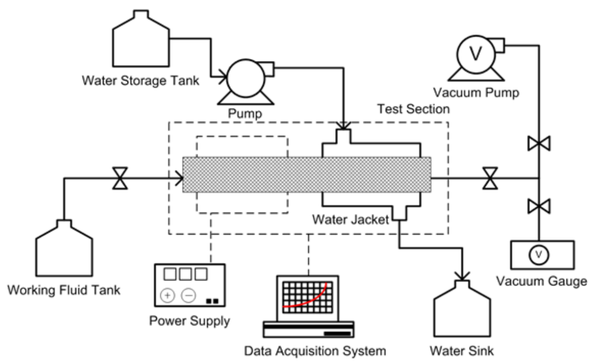


Fig 1. Heat pipe system

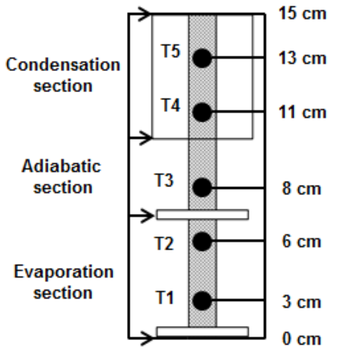
2. Experimental Setup and Procedure

In the present work, the heat pipe has two layers of stainless steel screen wire mesh as the wick structure and distilled water as the working fluid. Thermal performance of heat pipe was tested horizontally and vertically according to heat loads. Stainless steel 316L test sections having a sheath outer diameter of 6.65 mm (4.65 mm inner diameter) and length of 150 mm were prepared. Test section had evaporation region of 60 mm that heated by passing direct current between the copper electrodes. The adiabatic region of 30 mm was insulated by the glass wool and the condenser section was 60 mm in length. The condenser section cooled vaporized working fluid maintaining a constant temperature. Five thermocouples were installed to measure the temperatures along the test section (T1-T5). Two thermocouples were attached to the outer wall of evaporation region (T1 and T2). Another thermocouple was attached to the adiabatic region (T3). Two thermocouples measured the outer wall of condensation region (T4 and T5). Thermocouples locations are shown in Fig. 5.

Before filling working fluid, non-condensable gas was removed by vacuum pump. The fluid charge was rated based on the void volume in the wick structure. Distilled water was charged to evaporation section with 80% fill ratio in SS screen mesh wicked heat pipe. Uncertainty of water level due to instrumental error was less than ±5 %. The inlet temperature of coolant was maintained constant by chiller. The heat load range was 10W-50W.



(a) Experimental facility



(b) Test section

Fig 5. Schematic diagram for the experimental apparatus

The conditions of heat pipes were summarized in Table I. Total length of test section was 15 cm and its ratio was 6 : 3 : 6 of each section.

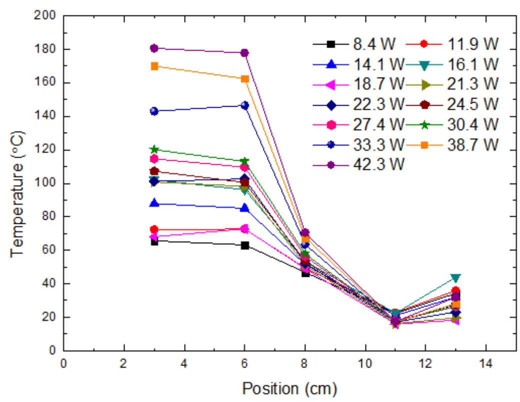
Table I: Initial Conditions

Initial Condition	Test
Water level	80 % in wick
Wick size	100 mesh
Porosity	0.62
Vacuum	14.6 kPa

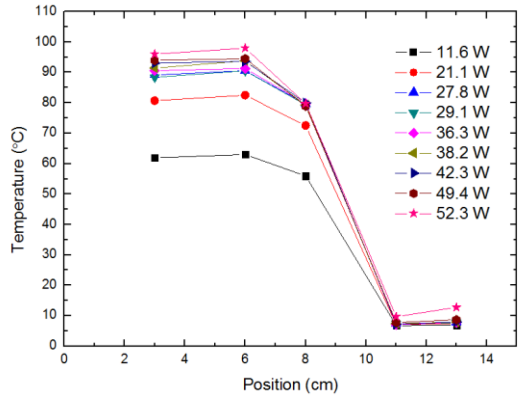
3. Results and Discussion

4.1 Temperature Distribution

Figure 6 shows the temperature distributions of horizontal and vertical heat pipe. The temperatures of evaporation section were increased as heat input increased. Temperature difference between the evaporation and the condensation sections were also increased as the heat input increased. Vertical heat pipe showed the enhancement due to enhanced convection from gravitational force.



(a) Horizontal heat pipe



(b) Vertical heat pipe

Fig 6. Temperature distribution of horizontal and vertical heat pipe according to position.

4.2 Thermal Resistances and Heat Transfer Coefficients

Fig 7 shows the thermal resistance and heat transfer coefficient of evaporation and condensation section.

Thermal resistance R can be presented by

$$R_{overall}\left(°C/W\right)=\frac{\overline{T}_e-\overline{T}_c}{Q_e} \qquad (1)$$

$$R_{evaporation}\left(°C/W\right)=\frac{\overline{T}_e-T_{sat}}{Q_e} \qquad (2)$$

$$R_{condensation}\left(°C/W\right)=\frac{T_{sat}-\overline{T}_c}{Q_c} \qquad (3)$$

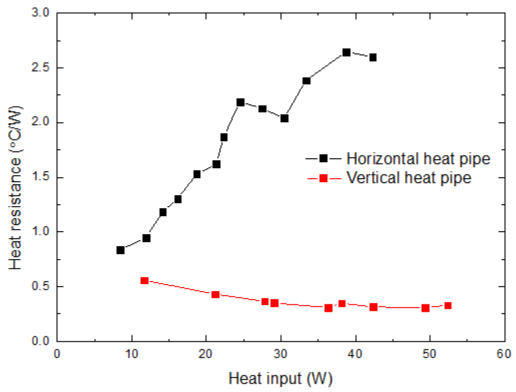
The heat transfer coefficient, h of heat pipe can be given by

$$h_{overall}\left(W/m^2°C\right)=\frac{q''_e}{\overline{T}_e-\overline{T}_c} \qquad (4)$$

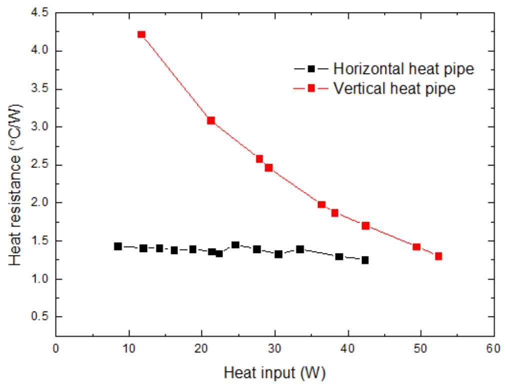
$$h_{evaporation}\left(W/m^2°C\right)=\frac{q''_e}{\overline{T}_e-T_{sat}} \qquad (5)$$

$$h_{condensation}\left(W/m^2°C\right)=\frac{q''_c}{T_{sat}-\overline{T}_c} \qquad (6)$$

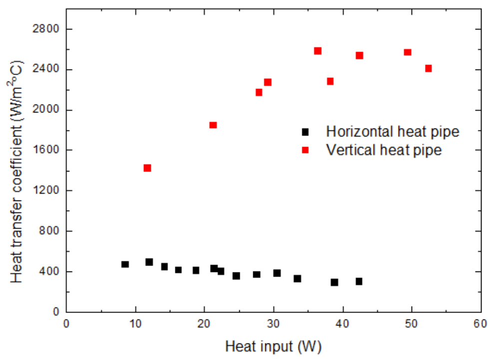
where, $\overline{T_e}$ is the average temperature of evaporation section (°C), $\overline{T_c}$ is the average temperature of condensation section (°C), and T_{sat} is saturation temperature (°C). From the experimental results and equations 1 and 2, thermal resistance and heat transfer coefficient can be found.



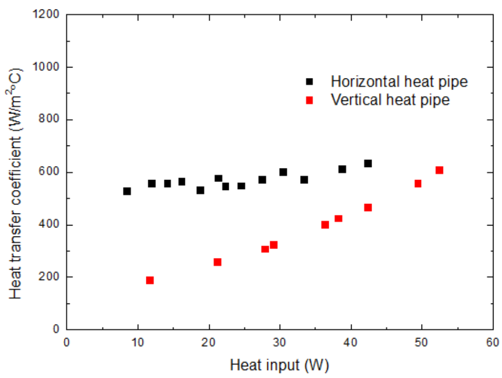
(a) Thermal resistance of evaporation section



(b) Thermal resistance of condensation section



(c). Heat transfer coefficient of evaporation section



(d) Heat transfer coefficient of condensation section

Fig 7. Heat performance of evaporation and condensation section.

Thermal performances of each test section were shown in figure 7 and 8. Vertical heat pipe had high heat transfer coefficient in the evaporation section because gravitational force helped the circulation of working fluid.

Heat resistance of vertical heat pipe was decreased in the range of 30–50 W. The heat transfer coefficient of the vertical heat pipe was increased from 150 W/m^2°C to 500 W/m^2°C, as the heat load was increased. Heat transfer coefficient of the horizontal heat pipe was decreased from 340 W/m^2°C to 200 W/m^2°C. This means that heat transfer was enhanced as the heat load was increased, in the case of the vertical heat pipe. Heat transfer coefficient of horizontal heat pipe was decreased because the temperature difference between evaporation and condensation section was increased. Vapor phase of the working fluid was increased. This means that the working fluid could not be filled in the upper side of the wick structure. Therefore, heat transfer coefficient of horizontal heat pipe was decreased.

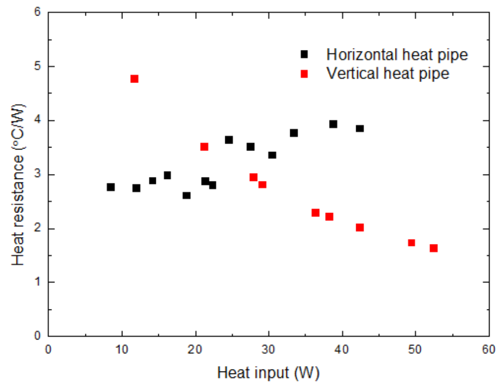


Fig 8. Overall heat resistance of heat pipe according to heat input.

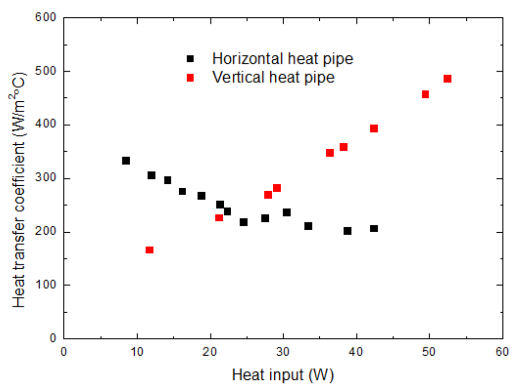


Fig 8. Overall heat transfer coefficient of heat pipe according to heat input.

4. Summary and Future Works

The main purpose of the research was the analysis of heat transfer behavior of heat pipe and the performance of heat transfer. The thermal performances of horizontal and vertical heat pipe were measured experimentally. Vertical heat pipe showed better performance compared to horizontal one, at high heat input region. The heat transfer coefficients of horizontal heat pipe were lower than vertical one because of gravitational force. Overall heat transfer coefficient of vertical heat pipes were enhanced to 28.5 % compared to the horizontal heat pipes. The horizontal heat pipes revealed high thermal resistance up to 54.3 % compared to vertical heat pipes. Therefore, vertical heat pipes analyzed better heat transfer performance than horizontal heat pipe. In the further study, is the enhancement of the heat transfer of heat pipe using nano-particles and different working fluids will be analyzed.

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