Length Effect on the Thermal Performance of a Heat Pipe for NPP Decay Heat Removal

Joseph Seo, Jae Young Lee*
School of Mechanical and Control Engineering, Handong Global University, Pohang, Korea,
82-54-260-1392, 82-54-260-1839, 791-708, jylee7@handong.edu

1. Introduction

Heat pipe is a heat transfer device which works passively by natural driven force of evaporation and condensation of a working fluid[1]. The heat pipe is made up of an evaporator region, an adiabatic region and a condenser region. A wick is fixed to the inside of a basic heat pipe and the condensate is returned to evaporator region by capillary force.[2]

After Fukushima accident, importance and necessity of passive safety for nuclear power plant have been emphasized. Due to its passive characteristic, heat pipe is seriously considered as an alternative device of the active safety system for removing decay heat from the reactor core[3, 4].

Among many possible applications of heat pipe in NPP, we considered the application to the control rod. In the situation of SBO(Station Black Out) due to BDBA(Beyond Design Basis Accident) in a PWR, control rods are dropped in to nuclear reactor core automatically. Thus, it is expected that applying heat pipe function to control rod can enhance reactor safety by removing decay heat of fuel assembly.

Considering the height of the control rod, L/D of the heat pipe would be larger than 400 if the given diameter is assumed to be similar to the diameter of the control rod. Thus, it may not be the matter for small heat pipes, it is necessary to consider the effects of L/D for the large L/D heat pipes. There for, length effect on the thermal performance of heat pipe for decay heat removal was experimentally investigated in this study.

2. Experiment

A special experimental facility which can measure the performance of vertical heat pipe with large length was designed. Also, SUS heat pipes with large L/D were manufactured to observe the L/D effect to the thermal performance.

2.1 Design of Test Section

In Fig. 1 and 2, the experimental apparatus which can test the heat pipe over 3000mm of height and 16.57mm of inner diameter was designed to investigate performances of heat pipes. For the first step to specify the length effect of heat pipe, heat pipe with 60,120 and 180 L/D(1000,2000 and 3000mm) were tested. The wick structure, shown in Fig.3, was specially manufactured by stainless fiber and fixed by high temperature furnace. The specific information of the heat pipe is shown in Table.1.

2.2 Measurement

Thirteen thermocouples (K-type and T-type) were mounted on the outside surface of pipe to check the temperature distribution. Temperature and volume flow rate of cooling water were also checked. Inner pressure was checked by pressure sensor attached in the upper end of heat pipe.

2.3 Experimental Loop and Procedures

In the same cooling condition(25°C and 4lpm), power was provided to the evaporator of heat pipe by direct heating method. If the surface temperature of heat pipe changes less than 1°C per 5minutes, it is considered as steady state. Surface temperature was measured at the steady state of every power step(50W~80W). Then the thermal resistance of heat pipes were calculated and compared.

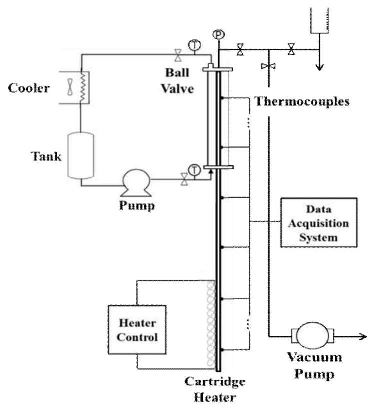

Fig. 1. Schematic diagram of experimental facility

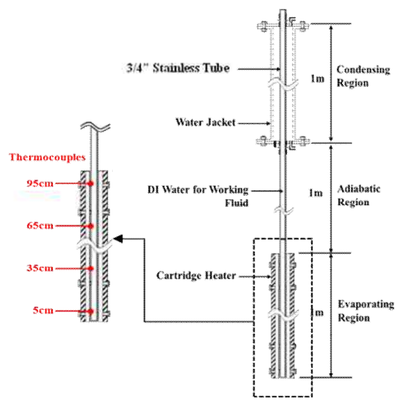

Fig.2 Construction of heat pipe module for thermal performance test

Table.1. Information of the experimental setup

Heat Pipe Type	Stainless wicked
Container	Stainless Tube(3/4")
EAC Length Ratio	1:1:1
Inner Diameter	16.57[mm]
Outer Diameter	19.05[mm]
Wick Thickness	3.5[mm]
Porosity	0.87
Pore Size	100[μm]
Working fluid	DI water
Filling Ratio	100%
Insulation	Glass fiber, Aluminum foil

Fig.3 Manufactured wick structures of heat pipes

3. Result and Discussion

Fig.4 shows the temperature distributions of heat pipes. In the steady state of normally working heat pipe, the temperature of evaporator is highest because heat from heater is applied directly to the evaporating region. In contrast, the temperature of condenser is lowest as the heat transferred to outside by phase change cooling. Ideally, the temperature of the adiabatic region is the same as the saturation temperature of the working fluid. These aspects are well shown in the temperature measurement result.

Using experimental result, temperature profile data against various heat input, thermal resistances of heat pipes were calculated. To confirm the effect of L/D, thermal resistances are plotted against heat input for various L/D of the pipes in the Fig. 5 bellow. It can be found that, the thermal performance of the heat pipe increases as heat input increases. However, as the value of L/D increases, thermal resistance also increases.

For the 1m heat pipe case, rapid surface temperature increasing occurred at 90W experiment because of capillary limitation. However, the limitation could not be seen up to 250W experiment for 2m and 3m heat pipe cases.

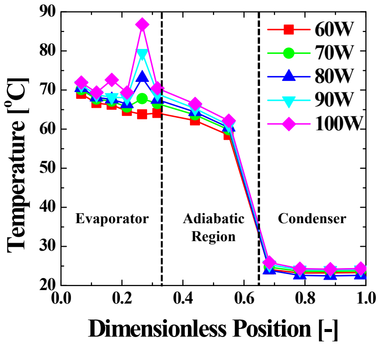

Fig. 4. Temperature distributions of 3m heat pipe

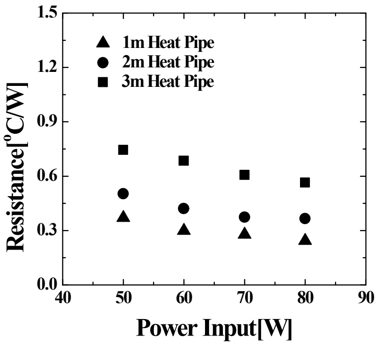

Fig. 5. Heat transfer coefficient of heat pipes

4. Conclusion

Through this study, the L/D effect on the thermal performance of the large L/D heat pipe for nuclear reactor has been studied. Thermal performances of various L/D heat pipes were checked by a series of experimental works. As a result, relationship between the heat input and the heat transfer coefficient of the heat pipe appeared clearly through experimental results. Performance of heat pipe increases as value of L/D increases. However, for the view of limitation, large L/D heat pipe showed better performance.

ACKNOWLEDGMENTS

This work was sponsored by National Research Foundation of Korea (NRF), granted financial resource from the Ministry of Science, ICT and Future Planning. (NRF-2013M2A8A1041443)

REFERENCES

[1] G.P Peterson, An Introduction to Heat Pipes Modeling, Testing and Applications, Wiley Inter-Science, 1976
[2] David Reay et al., Heat Pipes Theory, Design and Applications, Butterworth-Heinemann, 2014
[3] J. Y. Lee et al., Feasibility Study on Two-phase Thermosiphon for External Vessel Cooling Application of SFR, KNS, 2014
[4] Mochizuki, M. et al., "Heat Pipe Based Passive Emergency Core Cooling System for Safe Shutdown of Nuclear Power Reactor", Applied Thermal Engineering, 2014