Transactions of the Korean Nuclear Society Virtual Autumn Meeting
October 21-22, 2021

Design of an experimental facility with a high temperature heat pipe

Ho Sik Kim, Byung Ha Park*, and Chan Soo Kim
Korea Atomic Energy Research Institute, 111, Daedeok-Daero, Yuseong-Gu, Daejeon, Korea
[*]Corresponding author: bhpark@kaeri.re.kr

1. Introduction

A heat pipe is a key component of a heat pipe cooled reactor for space purpose. A bendable heat pipe of novel is required for the space utilization. The heat pipe with hybrid wick structures was suggested [1]. The hybrid wick consists of sintered metal wick and braided wire wick.

We manufactured sodium heat pipes with the hybrid wick for verifying the applicability to space nuclear reactor. It is necessary to experimentally verify the heat transfer performance of the manufactured sodium heat pipe. The operational limit of sodium heat pipes over 700°C are capillary limit and entrainment limit in the previous study [1]. In the experimental study of sodium heat pipes, however, if the heat input rate at the evaporator section and the heat rejection rate at the condenser section are not well controlled, sonic limitation occurs by overcooling at the condenser section. It makes normal operation and performance measurement difficult. Therefore, in the present study, the experimental facility was designed, in which the overcooling issue is minimized and the precise performance measurement are possible. The detailed specifications were calculated and decided with the parametric study.

2. Material and methods

2.1. Specifications of heat pipe

The working fluid was sodium. Material of the container tube was stainless steel 316L. The outer diameter was 12.7 mm and the wall thickness was 0.89 mm. The wick of condenser and adiabatic part was braided wire wick. The braided wire wick was measured 1.2 mm in thickness. At evaporator section, sintered metal wick, which was 20 μm in particle diameter, was added. It was at inside the braided wire wick. Both wicks are mechanically coupled. Fig. 1 shows the manufactured sodium heat pipes.

Fig. 1 Manufactured sodium heat pipes with hybrid wick structures

The design value of the operating temperature was 750°C and the target power is 500 W. The operational limit was controlled by entrainment limit and it is 1098 W. The experimental facility was designed based on 1000 W, which is slightly smaller than the operational limit.

2.2. Experimental facility

2.2.1. Design requirements and considerations

The overcooling issue can be divided into start-up operation case and normal operation case. Obviously, the overcooling occurs more easily during start-up operation than during normal operation because it is more difficult to balance the heat input and removal during the start-up operation. So, we chose the strategy of heating the entire heat pipe at the beginning of the start-up operation by the heating element of the furnace, as shown in Fig. 2. During the normal operation, unintentional heat loss and cooling is minimized by operating the heating element of the furnace. This enables precise performance measurement. In order to prevent overcooling during the normal operation, the cooling method at the condenser section is important. For stable heat removal, single-phase heat transfer was considered and air was selected as the cooling fluid for this purpose.

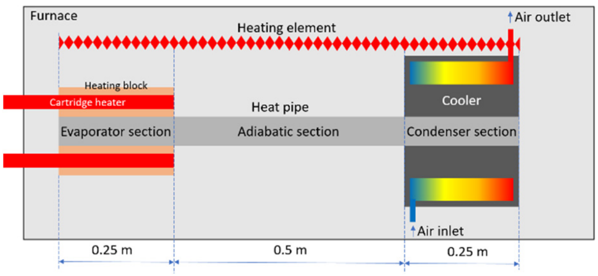

Fig. 2 Schematic diagram of experimental facility

The cooler at the condenser section was designed with the following considerations in mind: 1) installation of thermocouples on the surface of the heat pipe, 2) sealing of cooling channels, and 3) prevention of heat loss and heat transfer to unintended routes by direct contact between the cooler and the heat pipe (Fig. 3). The heat of the condenser section is transferred by conduction heat transfer through the powder material filling the gap between the cooler and the heat pipe. This heat is finally removed by convective heat transfer of the air supplied to the inside of the cooler. The filling material was chosen as a low thermal conductivity material in order to increase the temperature gradient in the gap and minimize the capacity of the air heater and blower. However, if it is too low, the heat may be transferred to an unintended route. Therefore, the SiO_2 powder (Polycrystalline) having the thermal conductivity one order of magnitude higher than that of the insulating material was selected.

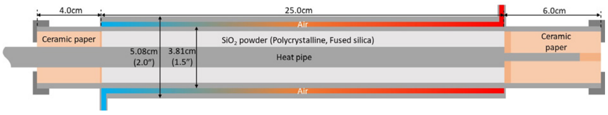

Fig. 3 Air cooler geometry

Finally, the possibility of manufacturing of the cooler was considered. Since it is difficult to manufacture the annular channel of the cooler by bending the flat plate, the cooler was manufactured by using ready-made tubes as the inner and outer walls of the cooler.

2.2.2. Performance evaluation methods of the cooler

For a parametric study, simple calculation was conducted with the steady-state thermal resistance model (Fig. 4) and the convection correlation and thermal energy equation for air flow. Then, the selected design from the parametric study was verified by the GAMMA+ code. The parametric study was conducted for size and combination of tubes used as the inner and outer walls of the cooler.

According to the size and combination of tubes, the gap thickness and the annulrkaar channel thickness of the cooler are determined. Five types (0.75", 1", 1.25", 1.5", and 2" outer diameter) of tubes were considered in the parametric study. In the parametric study, the combination of tubes with low pressure drop in the cooler, large gap thickness, and the surface temperature of the heat pipe approaching 750°C and not exceeding it was selected. The low pressure drop reduces the load on the air blower and the large gap thickness facilitates the installation of the heat pipe into the cooler. The 750°C is the design requirement considered in the manufacture of the sodium heat pipe.

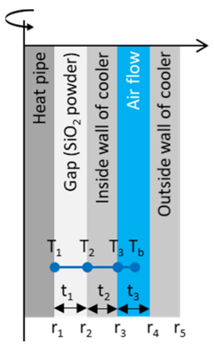

Fig. 4 Steady-state thermal resistance model

3. Results

From the parametric study with the simple calculation, the combination of 1.5" and 2" outer diameter tubes (Fig. 3) was selected and the surface temperature of the heat pipe was calculated as 743.1°C. For this tube combination, the GAMMA+ code similarly estimated the surface temperature as 745.0°C. Table I shows the main design specifications and performance estimation results of the GAMMA+ code.

Table I Main design specifications of the cooler

Dimensions	
Outer diameter of heat pipe (mm)	12.7
Length of condenser section (mm)	250.0
Thickness of gap (mm)	9.7
Thickness of inside wall (mm)	3.0
Outer diameter of inside wall (mm)	38.1
Thickness of annular channel (mm)	2.9
Thickness of outside wall (mm)	3.4
Outer diameter of outside wall (mm)	50.8
Materials	
Heat pipe	SS316L
Inside and outside walls of cooler	SS316L
Filling material of gap	SiO_2 powder
Thermal conductivity in gap (SiO_2 powder) at 500°C (W/m-K)	1.27
Calculation of GAMMA+ code	
Heat removal rate (kW)	1.0
Cooling fluid	Air
Boundary pressure (kPa)	101.325
Inlet temperature (°C)	130.0
Outlet temperature (°C)	167.5
Mass flow rate (kg/s)	0.0246
Average temperature of inside wall (°C)	308.1
Average temperature of heat pipe surface (°C)	745.0

4. Conclusions and future work

The sodium heat pipes with hybrid wick structure, composed of braided wire wick and sintered metal wick, were manufactured. In order to verify the performance of the sodium heat pipe, the experimental facility was designed. The designed experimental facility may minimize the overcooling problem at the condenser section that cause the sonic limitation and be capable of precise performance measurement by reducing the heat loss and heat transfer to unintended routes. The parametric study for the cooler was performed in consideration of manufacturability, and the performance of the selected design was verified by the GAMMA+ code. In the future, we plan to manufacture the experimental facility and conduct performance tests.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (Grant Code: 2019M2D1A1058139).

REFERENCES

[1] B. Park and C. Kim, "Parametric study of a high temperature heat pipe with hybrid wick structure", Transactions of the Korean Nuclear Society Spring Meeting May 13-14, 2021