Construction of a thermal performance test equipment for a high temperature heat pipe

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1. Introduction

The development of a bendable heat pipe is one of the main tasks for the development of a heat pipe cooled reactor for the space use. In the previous study, we designed and manufactured a bendable sodium heat pipe for space nuclear reactors [1]. We performed a thermal performance test for the prototype of a straight heat pipe by a passive cooling type performance test equipment [1]. However, it was difficult to operate the heat pipe with this equipment and precise performance measurement is impossible because natural convection and radiative heat transfer on the surface of the condenser section determined the heat removal rate or thermal performance, which is difficult to control and accurately evaluate. So we designed an experimental equipment for a high temperature heat pipe in which stable operation and precise performance measurement are possible [2]. In this study, we introduce the performance test equipment constructed based on the previous design study.

2. Material and methods

2.1. Specifications of heat pipe

Table I shows the main design specifications of the heat pipe. The working fluid is sodium. The length of the heat pipe is 1000 mm, and the outer diameter is 12.7 mm. The wick structure is the hybrid wick which consists of sintered metal wick and braided wire wick. The wick of condenser and adiabatic section is the braided wire wick. At evaporator section, the sintered metal wick is added at inside the braided wire wick and both wicks are mechanically coupled. The design values of the operating temperature and the thermal performance limit are 750°C and 1098 W, respectively. [1, 2]

Table I Main design specifications of heat pipe [1, 2]

Container tube	
Outer diameter of tube (mm)	12.7
Length of tube (mm)	1000
Thickness of wall (mm)	0.89
Sintered metal wick	
Length of wick (mm)	250
Radius of particle (μm)	20
Thickness of wick (mm)	1.0
Porosity (%)	38.7
Braided wire wick	
Length of wick (mm)	1000
Radius of wire (μm)	200
Thickness of wick (mm)	1.1
Porosity (%)	80.5
Materials	
Working fluid	Sodium
Container tube	SS316L
Braided wire wick	SS316L
Sintered metal wick	SS316L
Thermal performance	
Length of evaporator section (mm)	250
Length of adiabatic section (mm)	500
Length of condenser section (mm)	250
Operating temperature (°C)	750
Operational limit (W)	1098

2.2. Performance test equipment

2.2.1. Main components

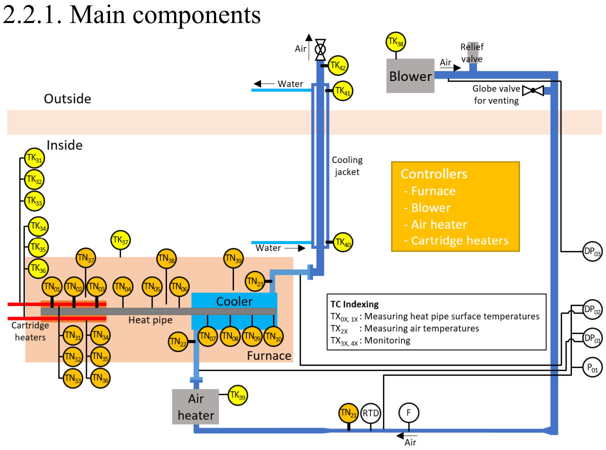

Fig. 1 Schematic diagram of test equipment

Fig. 1 shows the schematic diagram of the performance test equipment. The performance test equipment mainly consists of a heating furnace, a heat pipe, six cartridge heaters with a heating block coupled to the evaporator section, an air cooler coupled to the condenser section, a blower, an air heater, a cooling jacket, controllers, measuring instruments, and a data acquisition system. As shown in Fig. 1, the heat pipe, the cartridge heaters, and the air cooler are located inside the heating furnace in order to minimize the overcooling issue and reduce heat loss. The air cooler is coupled with the heat pipe by filling the gap between the cooler and the condenser section of the heat pipe with Al_2O_3 powder and filling the insulator at both ends of the gap, as shown in Fig. 2. In the previous design study, SiO_2 powder was filled in the gap [2]. However, the temperature gradient was too large in the gap, so the controllable range of the air inlet temperature of the cooler was too narrow. In order to widen the controllable range of the air temperature, it was changed to Al_2O_3, which has relatively higher thermal conductivity than SiO_2.

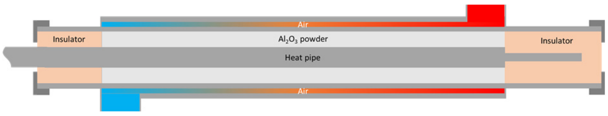

Fig. 2 Air cooler coupled to the condenser section

2.2.2. Measurements

The thermal performance of the heat pipe is evaluated by measuring the heat removal rate through the air cooler. For measuring the heat transfer rate, the volumetric flow rate of the air, the air temperature and pressure at the rear end of the flowmeter, the air temperature and pressure at the inlet and outlet of the air cooler need to be measured. Then, the heat transfer performance can be evaluated by the steady-flow energy equation as shown in Eq. (1).

$$\dot{Q} = \dot{m}\{(h_{out} - h_{in}) + {}^{1}/_{2}\,(V_{out}^2 - V_{in}^2)\} \qquad (1)$$

In addition, thermocouples were installed on the surface of the heat pipe to monitor the operating status of the heat pipe. As shown in Fig. 1, thermocouples and pressure transmitters were installed on the main components of the performance test equipment to monitor these devices. The measured data are acquired by the data acquisition system consisting of Kesight 34980A hardware and Kesight VEE Pro 9.33 software.

2.3. Operating procedure

1) Raise and maintain the environment temperature of the evaporator, adiabatic, and condenser section of the heating furnace to 600℃.
2) Supply air to the air cooler by the air blower.
3) Raise and maintain the inlet temperature of the cooler to 500℃ through the air heater.
4) Set the environment temperature of the condenser section of the heating furnace to be the same as the air inlet temperature of the cooler.
5) Heat the evaporator section of the heat pipe with the cartridge heaters.
6) Increase the power of the cartridge heaters step by step, and at the same time lower the air inlet temperature of the cooler step by step to maintain the surface temperature of the heat pipe around 700℃. At this time, adjust the furnace temperature of the condenser section to be the same as the air inlet temperature of the cooler.
7) Repeat 'Step 6' until the operational limit is reached.

Reaching the operational limit can be confirmed through the fact that when the power of the cartridge heaters increases, only the surface temperature of the evaporator section of the heat pipe rises and the surface temperature of the adiabatic and condenser sections of the heat pipe does not rise. As mentioned in the above operating procedure, the two main control parameters are the power of the cartridge heaters coupled to the evaporator section of the heat pipe and the inlet temperature of the air supplied to the cooler.

3. Results

Fig. 3 shows the heat pipe installed inside the heating furnace and coupled with the heating block and the air cooler. Fig. 4 shows the overall performance test equipment constructed. From a pre-test, the environment temperature of the heating furnace was maintained at 600℃, so reaching the sonic limitation could be avoided and it was possible to immediately operate the heat pipe by supplying heat to the evaporator section of the heat pipe. From the pre-test, it was confirmed that the stable start-up operation and normal operation of the heat pipe was possible. However, due to the lack of sodium or the accumulation of non-condensable gas, as expected, about half of the condenser section of the heat pipe did not work normally, and the performance limit of the air cooler was reached first (~650W), so the performance limit of the heat pipe could not be confirmed. In Fig 5, it can be seen that the surface temperature of the heat pipe is maintained near the operating temperature (~750℃) of the heat pipe only up to the midpoint of the condenser section (Condenser 2 in Fig. 5). In the future, the experiment will be conducted again with a heat pipe containing more sodium, to check the performance limit of the heat pipe.


Fig. 3 Heat pipe installed inside the heating furnace

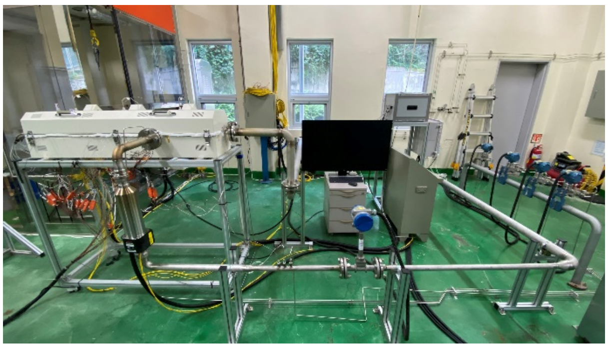
Fig. 4 Constructed performance test equipment

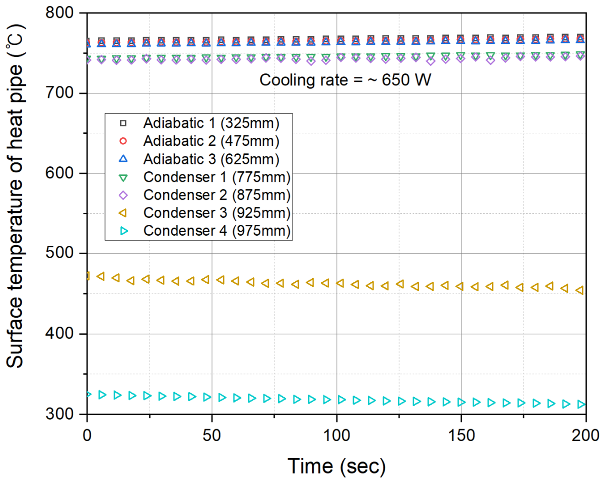

Fig. 5 Surface temperatures of the heat pipe when the performance limit of the air cooler was reached in the pre-test.

4. Conclusions and future work

The performance test equipment was constructed based on the previous design study. Through the preliminary test, it was confirmed that the performance test equipment was operating normally. Also, it was confirmed that stable and rapid start-up operation of the heat pipe is possible while avoiding the overcooling problem that is easy to occur during start-up operation. We plan to check the performance limit of the manufactured straight heat pipe through retest in the future. Then, the performance test of the heat pipe bent with the bending angle and bending radius as 90° and 35 mm will be performed with the same performance test equipment.

Acknowledgement

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