Experimental thermal evaluation of sodium heat pipe with different inclination angle

Dong Hun Lee, In Cheol Bang*
Department of Nuclear Engineering, Ulsan National Institute of Science and Technology (UNIST)
50 UNIST-gill, Ulju-gun, Ulsan, 44919, Republic of Korea
**Corresponding author: icbang@unist.ac.kr*

1. Introduction

Heat pipes can play an important role in nuclear fields such as microreactors, molten salt reactors, and spent nuclear pools as an indefinite cooling system due to its superior isothermal and passive heat transfer characteristics. Among them, the sodium heat pipe is widely used in systems such as microreactors as shown in Fig. 1. that operate at a high temperature usually 500°C to 800°C. The development of sodium heat pipe is mature since it was researched for space applications in LANL (Los Almos National Laboratory). However, still require various experiments to develop a technology of sodium heat pipe because heat pipes applied in nuclear fields are relatively longer than previous ones [1,2].

Several tasks have been performed to investigate the characteristics of sodium heat pipes and develop high fidelity simulation capabilities for microreactor applications [4-6]. A wide variety of experimental data are required because the thermal performance of heat pipes depends on various factors such as container geometry, wick properties, filling ratios, etc. Although there have been several experimental efforts to investigate the characterizing the sodium heat pipe, there is still a lack of experimental research about long heat pipes due to the difficult manufacturing.

This paper deals with a fundamental experiment of thermal performance of sodium heat pipe with different manufacturing to understand the thermal behavior and heat capacity, with a total length of 900mm and evaluated using an induction heating method. Several sensitivity parameters will be analyzed to evaluate the impact on the thermal performance of high-temperature heat pipes.

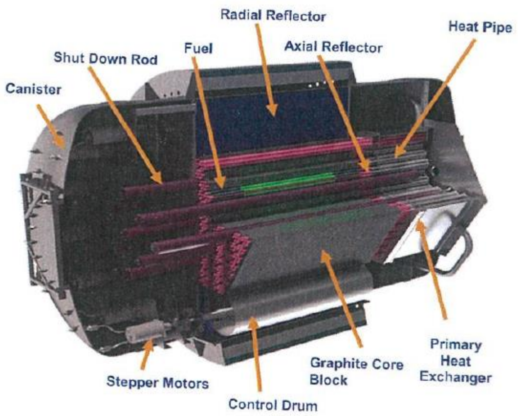

Fig. 1. Representative design of Microreactor [1].

2. Manufacturing of sodium heat pipe

The traditional manufacturing method of the heat pipe has limited especially in geometry. Especially, high mechanical strength metals such as stainless steel or alloy are usually used in sodium heat pipes that which is a difficult commercial manufacturing method for long heat pipes.

The additive manufacturing (AM) method is used for manufacturing the sodium heat pipe that can increase the degree of freedom in geometry and apply various combinations of wicks for performance enhancement. Previous studies investigate the advantages of additive manufacturing heat pipes, however, there are no experimental approaches for expanding AM technology to sodium heat pipes. To confirm the feasibility of sodium heat pipe manufacturing by AM, a comparison of the thermal performance with conventionally manufactured sodium heat pipe will be conducted.

Typical sodium heat pipes for microreactors operate at a high temperature, therefore, it is important to select proper powder material. 316 stainless steel (SS316L) that is usually used in sodium heat pipes for microreactor application, and Inconel 718 can operate at higher temperatures than stainless steel was selected as a powder material for additive manufacturing. Fig. 2. shows the additive manufacturing part for the sodium heat pipe.

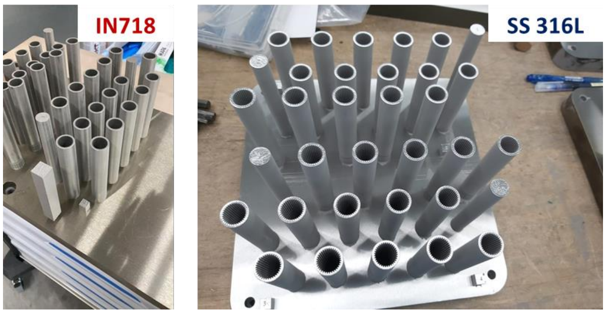

Fig. 2. Part of Additive manufacturing with different powder.

The welding process was conducted for connecting the AM parts since limitation exists in AM method for long length manufacturing due to thermal deformation. It is also important to optimize the length of each part and to weld it well as shown in Fig. 3.

Fig. 3. Part of Additive manufacturing with different powder.

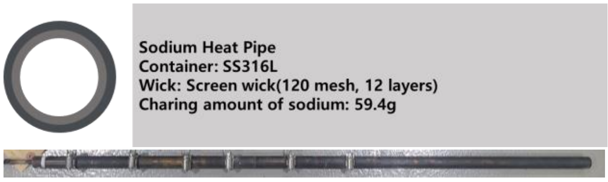

Fig. 4. Detailed information of screen wick sodium heat pipe.

For the comparison of thermal performance, a conventional sodium heat pipe that has a screen wick was manufactured as shown in Fig. 4.

3 Filling facility for sodium heat pipe

To manufacture AM heat pipe as the long length to investigate the thermal-hydraulic characteristics for advanced micro heat pipe reactors. Fig. 5. presented the detailed schematic of filling facility. There are two lines at the top of the heat pipe container for filling procedure.

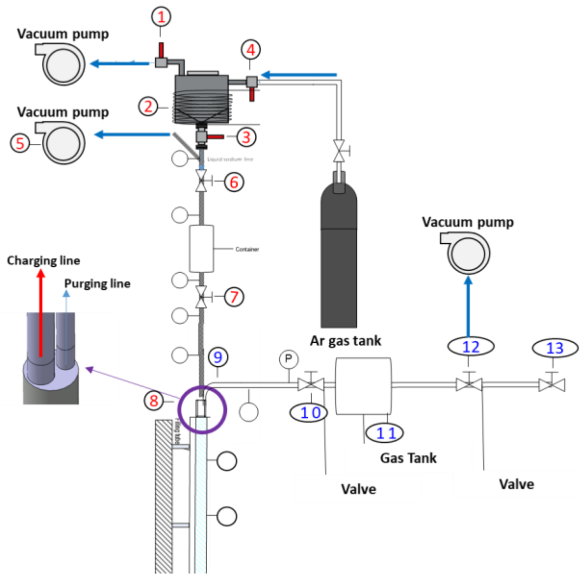

Fig. 5. Schematic P&ID diagram of sodium filling facility.

The specific filling process was described below.

(1) After putting a small amount of solid sodium in the vessel within the glove box, pull it out and connect to the charging loop maintaining a closed valve.
(2) Evacuate the sodium vessel using a vacuuming pump (1) and heat up using an electric heater that wrapped the vessel (2).
(3) Open the valves (3) (4) and inject Aragon gas to push the liquid sodium.
(4) Several TCs were set to check the solidification location and open the valves (6) (7) until sodium reached inside the heat pipe.
(5) Then, separated the heat pipe with charging loop (8).

After filling the liquid sodium in the heat pipe, non-condensable gas should be removed as possible for better performance.

(6) After liquid sodium solidifies in the heat pipe, open the purge valve (10).
(7) Evaporator is heated until the temperature at the tip of the condenser reaches 600~700°C. Then, We can assume that the sodium vapor successfully reaches the end of the pipe.
(8) Then closed valve (9) to prevent the vapor sodium leak out from heat pipe.
(9) Then remaining non-condensable gas in the expansion tank (11) is cooled by air convection to prevent the leakage of some sodium vapor that can exist, after that purge valve (12) (13) is open.
(10) Closed valve (9) and separated the heat pipe with purging loop.

4 Experimental setup

To compare the thermal performance of sodium heat pipe manufactured with a different method, a preliminary experimental facility was designed for the thermal evaluation of sodium heat pipe with various conditions such as inclination angle, wick design, filling ratio, and aspect ratio.
The test section as shown in Fig. 6. is composed of evaporator, adiabatic, and condenser regions that have a 1:1:1 length ratio. 300mm length of the induction coil was set and the temperature of the wall was measured by the pyrometer. The adiabatic section is surrounded by a thick insulator and the condenser section is opened to air cooling conditions.

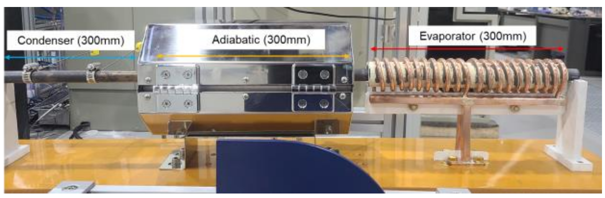

Fig. 6. Preliminary experiment facility of sodium heat pipe.

Preliminary check out of experimental setup were conducted for identifying the isothermal characteristics of sodium heat pipe as shown in Fig. 7. The temperature behavior of adiabatic and condenser section shows a typical behavior of sodium heat pipe from free molecular flow to continuum flow. Using this experimental setup, further investigation of sodium heat pipe will be conducted with the test matrix as shown in

Table 1. for evaluating the feasibility of sodium heat pipe using AM method, and preliminary evaluation to understand the thermal behavior and heat capacity.

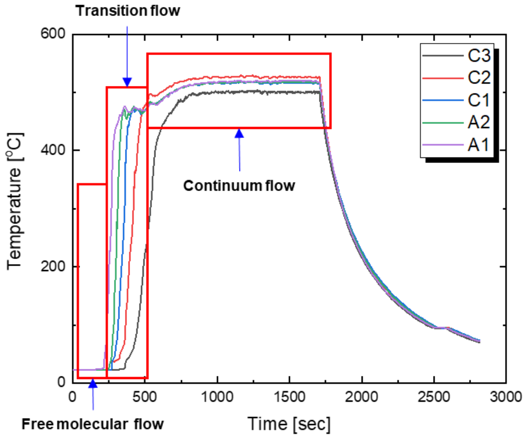

Fig. 7. Preliminary check out of sodium heat pipe performance.

Table I: Test matrix for thermal performance of heat pipe

	Manufacturing	Inclination Angle
HP1	Traditional method (Screen wick)	0-90°
HP2	AM method (Groove wick)	0-90°

5. Conclusions and Future works

To manufacture the long sodium heat pipe for advanced microreactor, an additive manufacturing method was used. The welding process was conducted for connecting the AM parts since limitation exists in AM method for long length manufacturing due to thermal deformation. For evaluating the thermal performance of sodium heat pipe, filling and experimental facility for the long scale has been constructed. Evaluating the feasibility of sodium heat pipe using AM method, and preliminary evaluation to understand the thermal behavior and heat capacity with different conditions will perform.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. M. Swartz, W.A Byers, J. Lojek and R. Blunt, Westinghouse eVinci Heat Pipe Micro Reactor Technology Development, International Conference on Nuclear Engineering. (ICONE 28), V001T04A018, 2021.

[2] J.W Sterbentz, J.E. Werner, M. G. Mckellar, A. J. Hummel, J. C. Kennedy, R. N. Wright, and J. M. Biersdorf, Special purpose nuclear reactor (5 MW) for reliable power at remote sites assessment report, No. INL/EXT-16-40741. Idaho National Lab.(INL), Idaho Falls, USA , 2017.

[3] Z. Tian, J. Zhang, C. Wang, K. Guo, Y. Liu, D. Zhang, W. Tian, S. Qiu, and G. H. Su, Experimental Evaluation on Heat Transfer Limits of Sodium Heat Pipe with Screen Mesh for Nuclear Reactor System. Applied Thermal Engineering, Vol 209, 118296, 2022.

[4] C. Wang, L. Zhang, X. Liu, S. Tang, S. Qiu and G.H Su, Experimental study on startup performance of high temperature potassium heat pipe at different inclination angles and input powers for nuclear reactor application, Annals of nuclear energy, Vol.136, 107051, 2020.

[5] C. Mueller. and P. Tsvetkov, Novel design integration for advanced nuclear heat-pipe systems, Annals of Nuclear Energy, Volume 141, 107324, 2020.