Additive manufacturing and charging procedure of high-temperature heat pipe for nuclear reactor application

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1. Introduction

High-temperature heat pipe charging with sodium as working fluid are attractive devices for passive and compact thermal managing of several energy systems such as microreactor, solar power generation, space reactor, and so on [1,2,3]. Utilizing the latent heat of vaporization of working fluid in the closed pipe, it can transport heat to long-distance passively and nearly isothermal. For proper thermal performance of heat pipe operation, proper container material, wick structure, charging are required. The container should have good compatibility with working fluid and be structurally safe in deformation from the long-term operation for a thermal path for supplying and releasing heat from external heat sources and sinks. The wick structure is a component that directly affects the capillary action, which is the principle of heat pipe operation. The more active capillary action by wick induced the circulation of the liquid working fluid, the more active the phase change can occur. Charging is also an important factor of heat pipe; fewer impurities of working fluid are required to increase the capillary force and maintenance of heat pipe.

Although there have been experimental and numerical studies such as thermal performance evaluation and operating limits for utilizing sodium heat pipes for nuclear application [4,5,6], there are few documents on devices that manufacture the container and charging working fluids in heat pipes. This paper describes the methodology related to heat pipe manufacturing and charging. To utilize liquid metal heat pipes in the nuclear reactor field, the design such as bending and the long scale must be manufactured than conventional heat pipes, and to do this, heat pipe manufacturing and charging method using 3D printing is evaluated in this paper.

2. Manufacturing and Charing Methods

The traditional method to manufacture the heat pipe has limited especially in geometry such as long scale, bending, or applying hybrid wick combined groove with screen mesh due to the difficulty of insert the wick in the container. Additive method (3D printed) heat pipe can solve does problem due to its high degree of freedom in geometry. To confirm the process of manufacturing and charging heat pipes using 3D printing, comparison the thermal performance of 2 HPs as described in Table I was needed.

Table I: Manufacturing and charging process of Heat Pipe

	Manufacturing	Charging
HP1	Traditional method	Charging
HP2	Additive method	Charging

2.1 Additively manufactured heat pipe

Several heat pipes studies have been conducted using the additive manufacturing method and showed that compared to conventional wick structure, 3D printing wick can improve thermal performance due to its roughness surface by laser powder [7,8]. However, the maximum length of a heat pipe that can be produced by 3d printing is approximately 30cm. To produce a heat pipe that is longer than 1m, a joint is made on the surface of the heat pipe, as shown in the Fig 1.

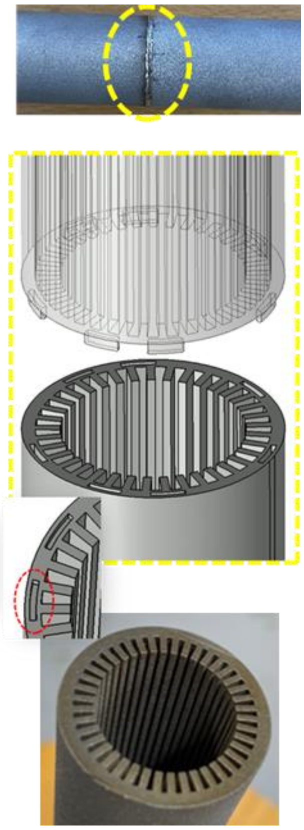

Fig. 1. Joint surfaces of 3D printed heat pipes for connection

To select the wick structure, the operating limit was evaluated at screen wick and groove wick. Limit calculation module structure and expressions used for each limit were summarized in Fig.2 and Table II.

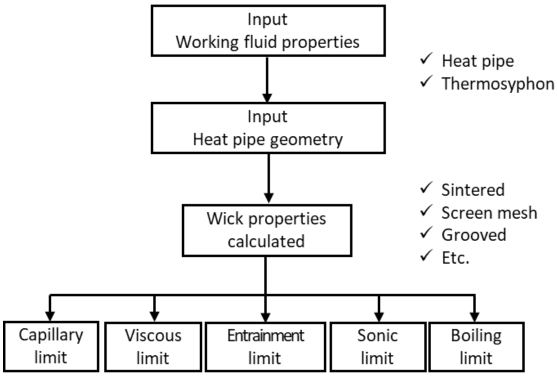

Fig. 2. Operational Limit calculation module structure

Table II: Heat Pipe Heat Transfer Limit Expression

Heat transfer limit	Expressions
Capillary limit	$\dot{Q} = \frac{\rho_l \sigma h_{lat}}{\mu_l} \frac{KA_l}{L_{eff}} (\frac{2}{R_{eff}} - \frac{\rho_l g L_{hp}}{\sigma} \sin\theta)$
Viscous limit	$\dot{Q} = \frac{A_v^2 h_{lat} \rho_v P_v}{16\pi u_v L_{eff}}$
Entrainment limit	$\dot{Q} = A_v h_{lat} (\frac{\sigma \rho_v}{D_{h,pore}})^{1/2}$
Sonic limit	$\dot{Q} = \frac{\rho_v c_v h_{lat} A_v}{(2(\gamma_v + 1))^{1/2}}$
Boiling limit	$\dot{Q} = \frac{4\pi L_{evap} k_{eff} \sigma T_v}{h_{lat} \rho_v \ln(D_{hp,i} / D_v)} (\frac{1}{R_b} - \frac{1}{R_{men}})$

The operating limits of the wick structures selected for comparison of 3D printed manufacturing evaluation can be found in Fig .3 and 4. A design with a high capillary limit was selected in the temperature range of 900K to 1200K. The detailed information of the screen wick and groove wick were organized in Table III.

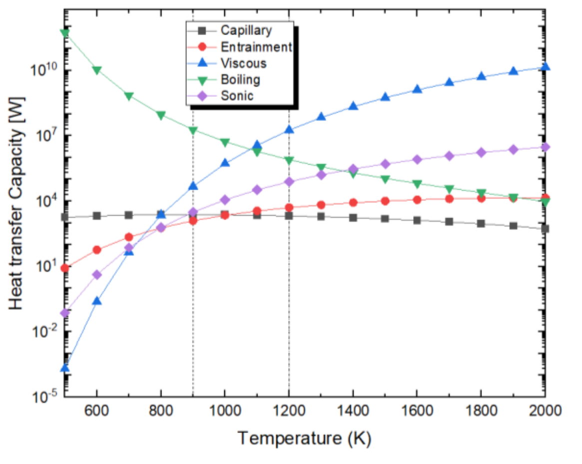

Fig. 3. Heat transfer operation limit of Screen mesh wick

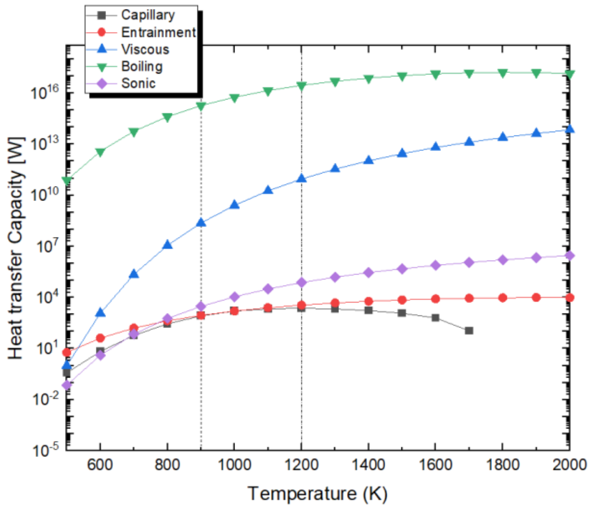

Fig. 4. Heat transfer operation limit of Groove wick

Table III: Selected Heat pipe geometry for manufacturing

Wick type	Sodium Heat Pipe		
	Geometry	Maximum Capacity	
		900K	1000K
Screen wick	Mesh number:120 Wire diameter:0.08mm Layer number: 3	1093W	1944W
Groove wick	Groove number:35 Width:0.6mm Thickness:0.8mm	937W	1665W

2.2 Charing Process of heat pipe

The charging procedure with sodium as a working fluid was performed as described below.

1. Prepare solid sodium
2. Sustain vacuum condition
3. Melting solid sodium using hot plate
4. Increase purity using bit of Ti or Zr piece.

5. Open Valve to move the liquid sodium to container.
6. Gas injection for pressure force
7. Working fluid charging
8. Degassing at high temperature(200~300°C)
9. Heat pipe sealing
10. Thermal test

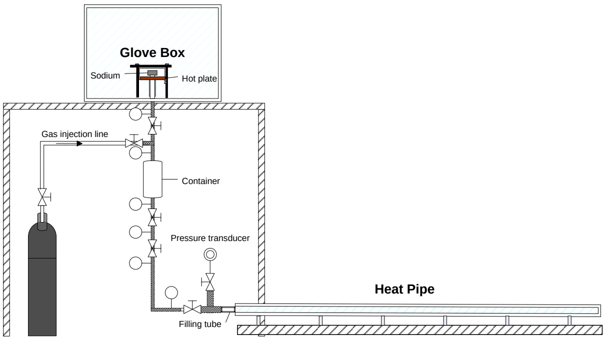

Fig. 5. Charing fluid facility for self-produce high temperature heat pipe.

The experimental device for charging is shown in Fig. 5. For filling the working fluid of the heat pipe with a length of up to 4m, the heat pipe is positioned in the lowest part of the filing facility with an inclination of 5~10 degrees from the horizontal. To prevent the solidification of liquid sodium in the filling tube, all pipes were wrapped with hot wire. Melting sodium in the solid-state inside the glove box and pass through the pipe by injecting the argon gas. After charging the working fluid, to remove the non-condensable gas inside the heat pipe, connect it to the vacuum pump at a temperature of 250°C for the decompression process as shown in Fig 6.

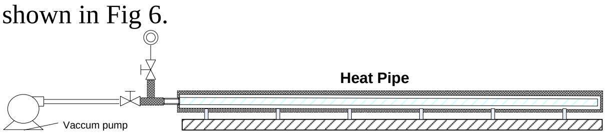

Fig. 6. Vacuuming facility for self-produce high temperature heat pipe.

3. Conclusions & Future work

To compare the conventional manufacturing and additive manufacturing (3D printed) heat pipes, the operation limit was evaluated according to the wick structure and the charging and vacuum facility for lab-made heat pipes was designed for thermal evaluation experiments under various geometry conditions. In the future, thermal performance evaluation of heat pipes manufactured and charged in different ways will be carried out. Through the productivity evaluation of 3D printed heat pipes, aims to overcome limitations such as bending and long scale, which were difficult to produce and contribute to various applications in the nuclear field.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2019M2D1A1072687) and the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (NRF2021M2D2A1A03048950).

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