Preliminary Experimental Evaluation of Natural Convection Loop for Liquid Gallium

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1. Introduction

To improve safety and economics for sustainable fast reactors, a variety of candidates of liquid metal coolants having excellent heat transfer property could be reconsidered. There are various liquid metals such as sodium and Lead-bismuth eutectic (LBE) being considered so far. Liquid gallium can be one of the potential candidates of coolant, too. The reason why we are interested in liquid gallium is technical advantages of liquid gallium as a nuclear coolant: The low melting point (29.78℃) in atmospheric pressure, the high boiling point (2,204℃), the low pressure of saturated vapor, explosion safety and low oxygen reactivity, and low toxicity of saturated vapor. Natural convection is the way to circulate fluid in a closed loop and this point is related to passive safety and reliability of nuclear power plant. The advantage provided by closed loops under natural convection is that they can transport heat from a source to a sink without a pump. The natural convection heat transfer in liquid gallium is important for a basic understanding of natural convection phenomena in liquids with very low prandtl numbers. It's important for the evaluation of decay heat removal capability for a fast reactor.

2. Experiment

2.1 The natural convection rectangular loop

The experiments were tested in three rectangular loops. Based on the power-volume ratio of scaling laws the tubes of the test loop are made of 316L stainless steel with outer diameters of 1/8", 1/4" and 1/2", respectively. The theoretical investigation suggested the following scaling laws for single-phase natural convection:

$$\left(Gr_m\right)_P = \left(Gr_m\right)_m \quad (1)$$

$$\left(St_m\right)_P = \left(St_m\right)_m \quad (2)$$

$$\frac{L_P}{L_m} = \frac{D_P}{D_m} = \frac{H_P}{H_m} = \frac{\left(L_h\right)_P}{\left(L_h\right)_m} \quad (3)$$

where, Gr_m is the modified Grashof number, St_m is the modified Stanton number, L is the total circulation length, D is the inside diameter, H is the loop height, and L_h is the heater length of the loop. The prototype of test loop is the TALL test facility [2]. Table I shows the dimensions of each test loop.

Table I: The scaling of experimental loop (mm)

Parameter	Prototype	1/8" loop	1/4" loop	1/2" loop
O.D.	33.4	3.175	6.35	12.7
I.D.	27.8	1.4	4.57	10.92
Height	6500	327	1068.5	2553
Length	1000	50	164	393
H.X. Length	1500	76	247	589

The schematic of the test loop is depicted in Fig. 1. The loop consists of a vertical heating and cooling section. The heating section (red part) is located lower than the cooling section (blue part) to occur natural convection easily. Fig. 2 shows that the test loop is heated by heating cable connected to DC power supply and cooled by temperature bath. The temperatures of the fluid of the test loop were measured by thermocouples.

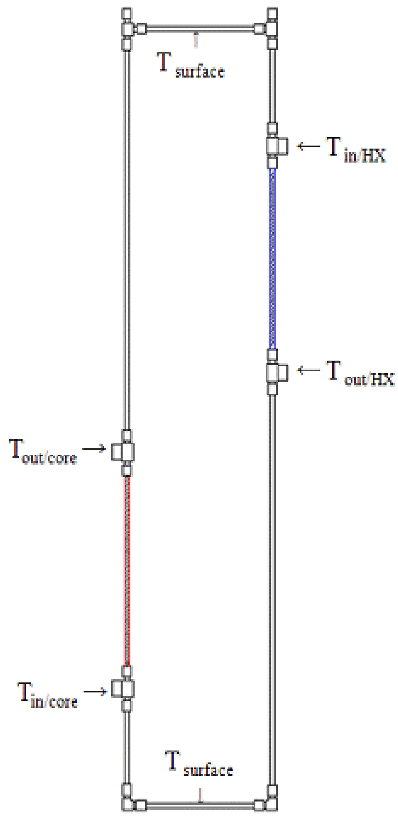
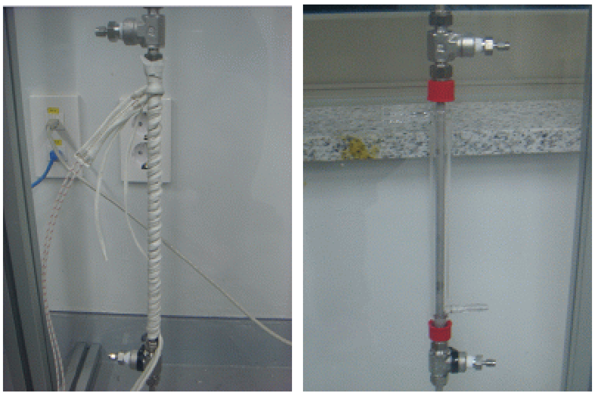


Fig. 1. Schematic of test loop



(a) (b)

Fig. 2. The parts of 1/4” natural convection rectangular loop: (a) Heating section and (b) Cooling section.

2.2 preliminary experimental data for gallium natural convection study

(a) (b)

Fig. 3. The 1/4" test loop

Fig. 3 shows the entire schematic of 1/4” test loop. Because of the low melting point of Gallium, the entire temperature of test loop must be maintained above 30℃. Therefore, we put heating cables heating on test loop to maintain temperature. (Fig. 3(b))

Before doing the experiment about the gallium, distilled water was used as working medium. The temperatures of the fluid at different locations of the heater tube (core), heat exchanger and horizontal part of test loop are measured. The test loop was operated under atmospheric pressure. The experimental conditions are as follows: heat input power to the heating section Q=20, 40, 60W, fluid temperature at the inlet of the heated tube T_{in_core} = 20-25℃, and fluid temperature at the outlet of the heated tube T_{out_core} = 30-95℃. The flowrate in the heated test tube is power-dependent.

Fig. 4 shows the graph of temperature by time and indicates that natural convection is occurred according to given heat power.

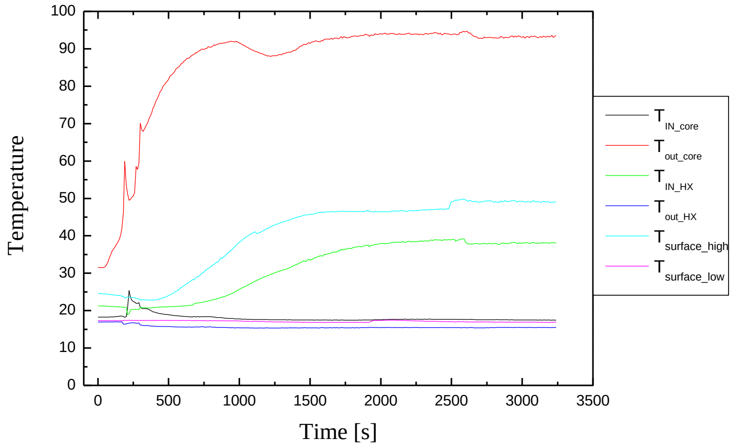


Fig. 4. The temperature data of 1/4” data (Q=60W)

3. Conclusions

We tested a natural convection loop designed according to the power-volume ratio of scaling laws for liquid gallium natural convection study. We confirmed natural convection of test loop by distilled water experiment. Next, we will confirm natural convection of gallium using 1/4" and 1/2" loop and influence of scaling laws.

The experiment will show the natural convection capability of gallium by determining a flowrate formed according to a level of the heat input. By using the dimensionless number, the correlations in the tube at natural convection of gallium will are represented. In the experiment the heat transfer characteristics of liquid gallium as a coolant will be investigated.

It is highly important to perform thermal-hydraulic tests on a scaled gallium-cooled system. The current study can contribute to advanced designs of passive decay heat removal system with adopting a safer coolant and intermediate loop to secure the safety more tightly of the current typical designs of sodium-cooled reactor with the safer coolant loop.

REFERENCES

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[2] Weimin Ma, Aram Karbojian, Bal Raj Sehgal, Experimental study on natural circulation and its stability in a heavy liquid metal loop, Nuclear Engineering and Design 237 1838-1847 (2007).