Experimental Evaluation of Natural Convection Loop for Liquid Gallium

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1. Introduction

There is an emphasis generally to passive safety in nuclear reactor design so that reactors can be made more tolerant of failing and have less dependence on engineers. The safety issues of liquid metal fast breeder reactors (LMFBRs) are important due to the fact that a highly reactive and hazardous coolant like liquid sodium. The sodium fast reactor (SFR) is a concept proposed by the Generation IV and is considered as the prime candidate as coolant in the medium-term future. [1] As liquid metal coolant, liquid gallium also can be one of the potential candidates of coolant as shown in table 1.[2] 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. In this work, we focus on the natural convection flowrate and heat transfer coefficient of liquid gallium.

Table I. Thermo physical properties of liquid metals

	Na	Pb	LBE	He(gas)	Ga
Atomic Weight	22.997	207.21	208	4	69.723
Melting Point (°C)	97.8	327.4	123.5	n/a	29.76
Boiling Point (°C)	892	1737	1670	-267	2204
Density (kg/m^3)	880	10500	10300	0.178	6095
Specific Heat (J/kg-K)	1300	160	146	5200	381.5
Thermal Conductivity (W/m-K)	76	16	11	0.152	29
Viscosity (cP)	0.34	2.0-2.5	1.7	0.018	1.810

2. Experiment

2.1. Description of test loop

The experiments were carried out in a uniform diameter rectangular loop built with 316L SS tube of inside diameter 10.92mm and outside diameter 12.7mm (1/2").

Table II: The dimensions of the test loop

Parameter	Prototype	1/2" loop
O.D.	33.4mm	12.7mm
I.D.	27.8mm	10.92mm
Height	6500mm	2553mm
Length	1000mm	393mm
H.X. Length	1500mm	589mm

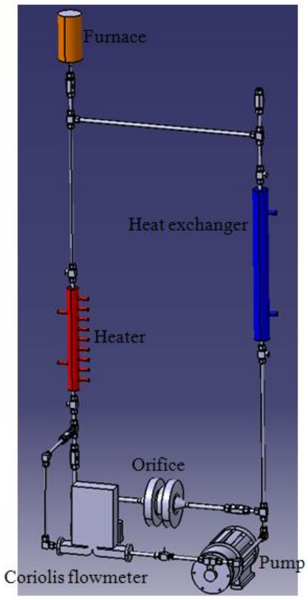

Fig.1. Schematic of the test loop

The prototype of test loop is the TALL test facility and table II shows the dimensions of the test loop. [3]

The loop consists of a vertical heating and cooling section as shown in Fig.1. The heating section (red part) is located lower than the cooling section (blue part) to occur natural convection easily.

Fig.2. General view of the test loop

Test loop can be operated under natural and forced convection conditions as shown in Fig. 1 and Fig. 2. To measure natural and forced convection flowrate, the orifice and Coriolis mass flowmeter were used respectively. Thirteen 1.6mm diameter K-type thermocouples were used to measure the surface temperature of tube in a heating section and liquid gallium temperature in heating and cooling section.

2.2 Experimental data for gallium natural convection study

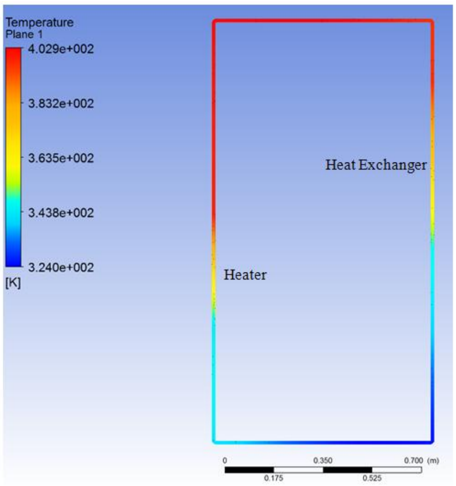

Fig. 3. The result of CFX (Q=1.32kW)

The first aim of this work is to investigate the natural convection flowrate of liquid gallium of each different power condition on the numerical results obtained with CFX code as shown in Fig. 3. The experiments were conducted in the ranges of 0~2.5kW as shown in Fig. 4. The experimental results were compared with CFX and calculated value using eq.(1) and the errors for the three validations were found to be in the average values of 40%(CFX) and 48%(1) respectively. [4]

$$\dot{m} = \left(\frac{2\rho_0^2 \beta g \Delta H P}{C_P R}\right)^{1/3} \qquad (1)$$

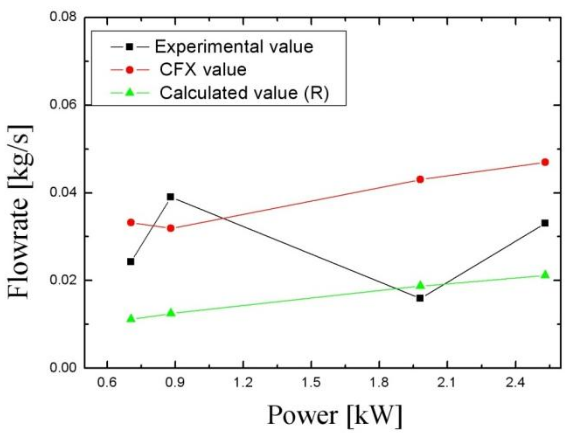

Fig.4. The experimental results of natural convection flowrate with CFX and eq.(1).

The experimental results of heat transfer coefficient of liquid gallium were compared with Churchill et al.(2), N.Sheriff(3) as shown in Fig. 5.

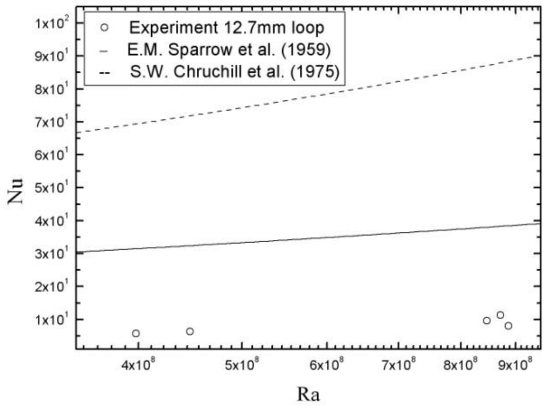

Fig.5. The experimental results of heat transfer coefficient compared with S.W. Churchill et al.(2) and E.M. Sparrow et al(3).

We can check the experimental results are much lower than existing correlations. [5,6]

$$\mathrm{Nu} = \left\{0.825 + \frac{0.387(\mathrm{Ra_L})^{1/6}}{\left[1+(0.492/\mathrm{Pr})^{9/16}\right]^{5/27}}\right\}^2 \qquad (2)$$

$$\mathbf{0.5497} = \frac{\mathbf{Nu_x}}{(\mathbf{Gr_x \cdot Pr^2})^{1/4}} \qquad (3)$$

3. Conclusions & Future Work

Motivated by the increasing interest in passive safety of liquid metal-cooled fast reactors, a study of the liquid gallium natural convection in the test loop was carried out. dynamic behavior observed in experiments carried out in a single-phase natural circulation loop, but the experimental data were much lower than existing correlations as shown in Fig. 5.

Such contrasted conclusions indicate that further experiments are obviously needed to analyze the quality of liquid gallium in the natural convective heat transfer process, and so we will make up for experiment and obtain more accurate data.

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