Thermal-hydraulic analyses of a single-phase natural convection loop for liquid gallium with computational fluid dynamics and MARS-LMR code

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1. Introduction

This study considers gallium as alternative liquid metal coolant applicable to safety features in terms of chemical activity issue of the sodium. The attractive properties ensure that gallium can play an important role in nuclear safety as an alternative coolant of the decay heat removal system of the SFR. To investigate and predict the heat removal capability of liquid gallium, it conducted safety analysis by using computational fluid dynamics and MARS-LMR code. Figure 1 shows the natural convection experimental facility for liquid gallium.

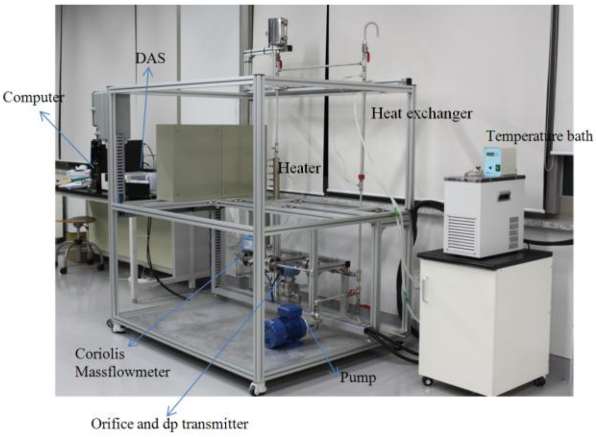

Fig 1. The Schematic of experimental facility

2. Methods and Results

2.1 Prediction of natural convection capability for liquid gallium using equation

For a given power, the mass flowrate may be obtained and anticipated as following [1]:

$$\dot{m} = \left[\frac{2\beta\rho^2 g\Delta HQ}{C_p R}\right]^{1/3} \quad (1)$$

where, β is the coefficient of thermal expansion, ρ is the density, g is the gravity, Q is the power, ΔH is the elevation difference between the center of heater and heat exchanger, R is the flow resistance parameter, and C_p is the specific heat capacity.

2.2 Computational fluid dynamic model

A finite element approach was used in this study for the analysis of the steady-state conditions that was reached when natural convection becomes the main driven force as cooling mechanism. The simulation was done in a 2D geometry as shown in fig 2. The modeling simplification had been divided by a heater, a heat exchanger, and two horizontal parts instead of a fully geometry description.

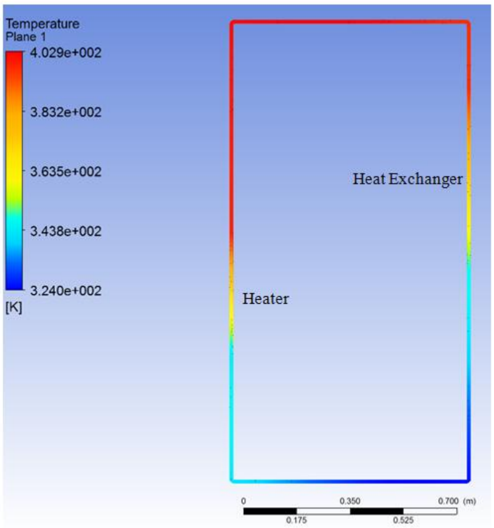

Fig 2. Prediction of emperature contours in the experimental facility

2.3 MARS-LMR model

In this study, MARS code was also selected to analyze the thermal-hydraulics of the experimental facility. Although MARS was originally intended for a safety analysis of light water reactor [2], we have managed to modify this code into a new code, called MARS-Ga, which is applicable for Ga-cooled systems. This code was made by modifying physical properties in MARS while maintaining its original numerical methods. Figure 3 indicates the nodalization of the experimental facility.

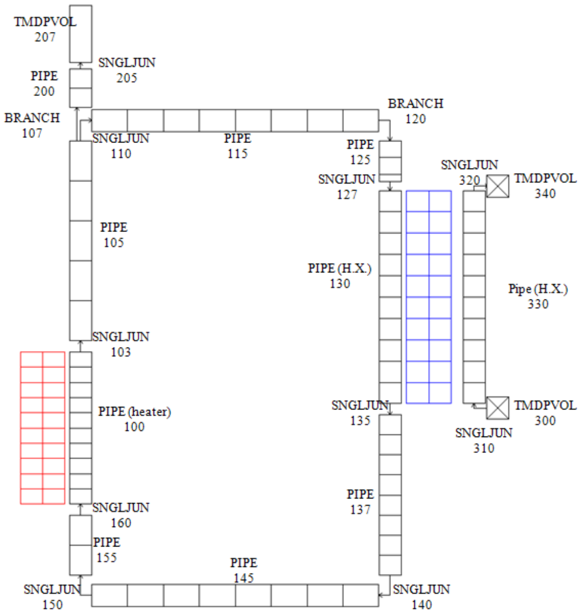

Fig 3. Nodalization of experimental facility adopted for MARS-LMR code

2.4 Comparison with the value of prediction using eq.(1) , CFD, and MARS-LMR code

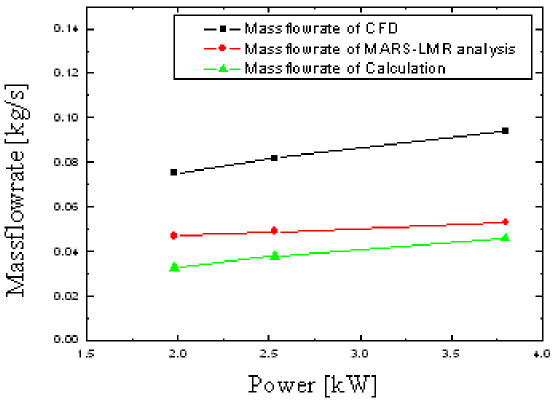

Fig 4. Comparison with the value of prediction, CFD, and MARS-LMR code

Fig 4 shows the comparison with the value of prediction by using eq.(1), CFD, and MARS-LMR code according to a level of the input power. It can confirm that the safety analysis results lie between those of CFD and calculation and anticipate the experimental value will be located in same region like those of MARS-LMR code.

3. Conclusions

This paper discusses the safety analysis results by using MARS-LMR code and computational fluid dynamics to investigate the heat transfer characteristics in a single-phase natural convection loop as shown in fig 1. The loop consists of a vertical heating and cooling section and working fluid is liquid gallium. The safety analysis results show the natural convection capability of gallium by determining the flowrate formed according to a level of the heat input. This study can contribute to an advanced design of passive decay heat removal system with adopting a safer coolant to secure the safety more tightly of the current typical designs of sodium-cooled reactor.

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