Design and Thermal Analysis of an LBE Capsule Mockup

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1. Introduction

National nuclear R&D programs in Korea are mainly focused on the development of SFR and VHTR. The LBE capsule has been studied to perform high temperature irradiation tests of the SFR materials [1-4]. An irradiation test by using an LBE capsule is expected to begin from 2010 for the SFR fuel and materials. The test will be performed in the OR-5 test position of the HANARO reactor at KAERI. In an effort to enable the required design and performance of an LBE capsule and to provide design recommendations for establishing the fabrication techniques for an LBE capsule development, a capsule mockup, which was designated as 09M-01K, was designed and manufactured. In 2009, heat transfer experiments will be conducted to measure effective heat transport coefficients needed for heat transfer calculations in higher performance regimes.

This paper includes the R&D activities required to verify the design and performance of an LBE capsule and to understand the thermal characteristics of an LBE capsule mockup.

2. The design and fabrication of an LBE Capsule Mockup

The design concept of the capsule mockup was created by applying a double containment concept for temperature control and safety in a research reactor. The overall shape of an LBE capsule is quite similar to the present standard capsule except for the use of an LBE as a thermal media. From a series of thermal analyses [1, 2], the dimensions of a mockup were determined. The main body of the capsule mockup, which is about 56mm in diameter and approximately 1361 mm long, consists of a heater of 13.3 kW as a simulated specimen, LBE as a thermal media, an internal tube as an LBE container, and an external tube. In order to simulate the specimen space such as fuel or materials in a capsule, a heater is placed in a center of an LBE cylinder. A gas gap exists between the LBE container and the external tube for heat transfer purposes.

In this study, a mockup capsule was fabricated for the heat transfer experiments which will be performed under the HANARO hydraulic conditions. The capsule mockup was instrumented with 14 type K thermocouples at 3 different levels for monitoring and controlling the surface temperature of the heater's cladding, bulk temperature of an LBE, and the surface temperature of an internal tube (LBE container). The dimensions of the fabricated mockup are shown in Table 1. Fig. 1 is a photograph of the instrumented capsule's mockup that was used.

Table 1. Mockup Design Characteristics of 09M-01K

Main body	External tube diameter/thickness(mm)	56/2
	Internal tube diameter/thickness(mm)	52/1
	Gap between external and internal tube(mm)	1
Heater	Outside diameter(mm)	26.5
	Power(kW)	13.3
	Hot length(cm)	600
Thermal media	LBE(44.5w/o Pb+55.5 w/o Bi)(kg)	10
Instrument	Thermocouple(k-type, 3 different location)(ea)	14

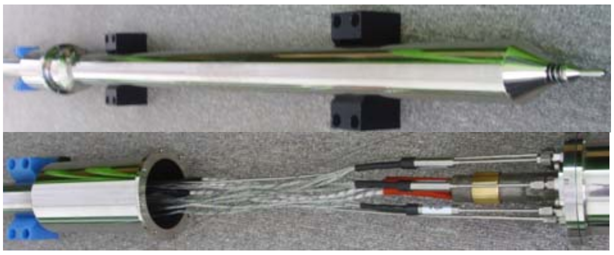

Fig. 1 Photograph of the Capsule's Mockup (09M-01K)

3. Thermal Analysis

The temperature calculations for a capsule's mockup are performed using a finite element analysis program, ANSYS [5]. The analysis model for the circular cylinder of double containment concept is generated by the coupled-field elements of PLANE223 with a 2-D structural-thermal field. Fig. 2 shows the two-dimensional analysis model for a quarter sections with a central heater as a heat source. In the reactor, the specimens, the LBE, and the internal and the external tube of a capsule act as a heat source due to a high γ-ray flux. However, for this numerical study heating rates for the material specimens, the LBE, and the structural materials were not considered except for only the heat flux of a heater ($43.75kW/m^3$).

The boundary conditions in the FE analysis are symmetrical for the x and y axis in the model. The heat transfer coefficient used in this study is 33.0 KW/m^2.C [6], which will be evaluated from the heat transfer experiments, and the reactor coolant temperature is about 40 ^{o}C.

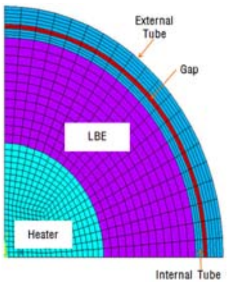

Fig. 2 Typical finite element model of the circular cylinder.

The temperature data for a circular cylinder with a heater as a heat source of specimen are obtained by a finite element analysis.

Fig. 3 shows the temperature distribution of an LBE capsule's mockup with a wall thickness of 2.0 mm and a gap size of 1.0 mm and its temperature profile in the radial direction. The maximum temperature is around 901 ^{o}C at a heater surface. The temperature profile at the specimen positions is found to be relatively uniform as compared with the data of a typical capsule using a solid thermal media [4]. But, the temperature distribution near a gap is decreased rapidly like a typical capsule using solid thermal media.

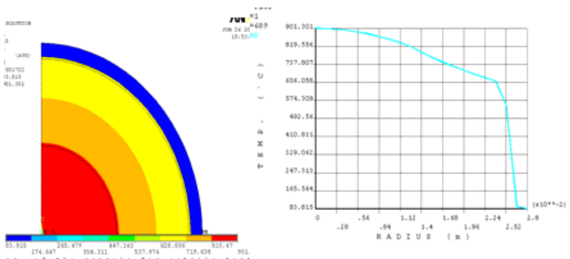

Fig. 3 Temperature distribution (a) and temperature profile in the radial direction (b) of the mockup

4. Conclusions

A full-scale mockup of an LBE capsule was designed and successfully fabricated for the heat transfer experiments. The experiment using a single channel test loop is underway to get detailed temperature data at 3 different locations. From the comparison of thermal analysis results and experimental data, thermal characteristics of an LBE capsule mockup will be quantitatively evaluated. This data will be also used directly for the safety evaluation of an LBE capsule.

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