Simulation of TRISO fuel irradiation by using surrogate heating elements

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1. Introduction

KAERI has been endeavoring to develop the TRISO (Tri-structural Isotropic) coated particle fuel technology as a part of the Korean VHTR (Very High Temperature modular gas cooled Reactor) project started in 2004, and it is planning an irradiation test of the TRISO fuels in the research reactor, HANARO in Korea for the evaluation and prediction of the irradiation behavior of the fuel.

Design of a non-instrumented capsule for use in the HANARO irradiation test is in progress. The capsule has to provide a high temperature circumstance for the TRISO coated particle fuel held in the capsule and withstand the thermal load imposed on its metallic tubes surrounding the test specimen. Moreover, the capsule should satisfy a variety of requirements related to the nuclear and the geometrical characteristics of the reactor core.

In this study, thermal load simulations and verification experiment of a very high temperature irradiation of TRISO coated particle fuels in HANARO research reactor were carried out by using the MgO and the graphite heating elements to verify the feasibility that irradiation rod designs can embody the high temperature of the fuel and withstand the high temperature environment. Results of the experiments were also used to develop and verify a COMSOL[1] based finite element heat transfer model that will be used as a basis for an optimum design of an irradiation test rod.

2. Methods and Results

2.1 Experiment

Experiment apparatus was developed to simulate the conductive and convective heat transfer from the TRISO fuels to the coolant in the HANARO research reactor. Schematic diagram of the apparatus is shown in Fig. 1.

The heating rod shown in Fig. 1(b) corresponds to an irradiation rod in an actual irradiation in the HANARO. The heating rod consists of a heating element, an encapsulating tube, and gap gas. The heating element is made of MgO, the tube inconel 600, and the gap gas neon. The experiment by using a graphite heating element has not been carried out but a COMSOL simulation was included in this study. The heating element is placed in the middle of the tube and neon gas in the gap blocks the outward heat transfer. The heating rod is cooled by the water that flows along its external surface.

The heat flux from the TRISO fuels in HANARO research reactor is the sum of γ-heat from the fuel matrix and decay heat from the TRISO fuels. The heating element is a surrogate for the TRISO fuels and can simulate the heat flux of the fuels by producing electric heat at the same rate. A physics code, MCNP was used to calculate the heat generation by the TRISO fuels and the matrix in HANARO research reactor.

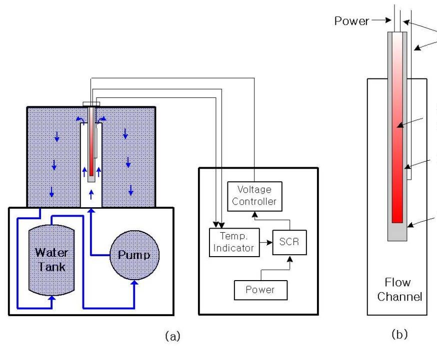

Fig. 1. Output Schematic of the simulation experiment: (a) experiment apparatus, (b) details of the heating rod in the flow channel

The rate of heat generation in the heating element is regulated by controlling the voltage supply to the element. Temperatures of the heating element and the inner surface of the tube are monitored. Experiments have been carried out for a few cases with different dimensions of the heating rod as listed in Table 1.

Table I: Experiment Conditions

Case	Tube OD	Tube ID	Heater OD	Gap Size	Filling Gas
1	16mm	14.4mm	11.8mm	1.3mm	Ne

2.2 FE Model Buildup and Verification

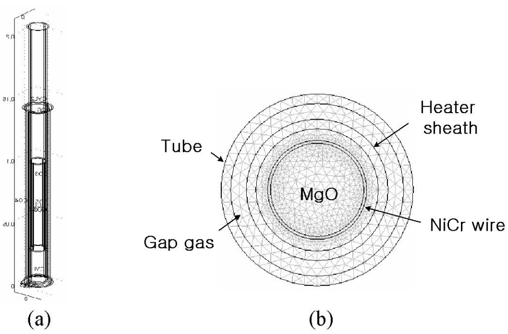

Fig. 2. (a) 3-D FE model of the MgO heating rod, (b) Cross-sectional view.

Fig. 2 shows a COMSOL based 3-D finite element model of the MgO heating rod and its cross-sectional view. The heat flux from the TRISO coated particle fuel was modeled by defining an equivalent heat flux at the surface of the heating element. Convective heat transfer to the flowing water was also considered.

Thermal properties for Ne, inconel 600, MgO and graphite were obtained from Perry's Chemical Engineers' Handbook, and the Matweb. [2][3][4]

The calculation results obtained from this 3-D model were compared with those of the experiments for the cases in Table 1.

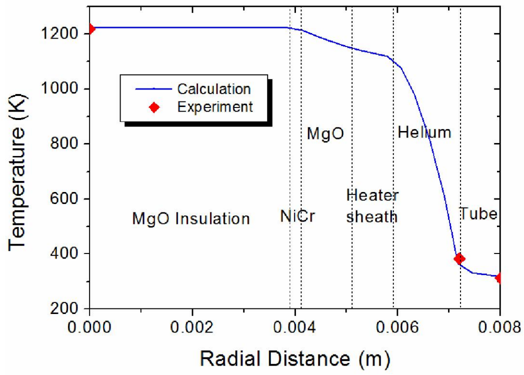

Fig. 3 Temperature comparison across the cross-section of the heating rod between the experiment and the calculation

FE model was evaluated by comparing its results with those of experiment as shown in Figure 3. Temperatures of the heating element, the inner and the outer surfaces of the tube showed quite a good agreement between the analysis and the experiment. Temperature of the tube inner surface showed the biggest difference due to the radial position of the sensor was not clearly identified.

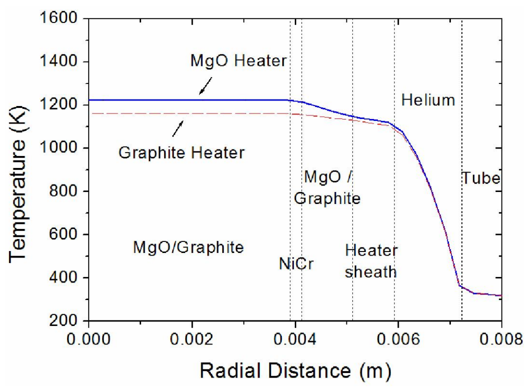

Fig. 4 Temperature comparison across the cross-section of the heating rod between the MgO and the graphite heater

Temperatures across the cross-section of the heating rod were calculated for the case of graphite heater and were compared with those of the MgO heater case as in figure 4. The maximum temperature of the graphite heater was 1161K, which was 61 K lower than that of MgO heater. The difference was caused by the lower heat conductivity and higher radiation emissivity of the graphite when compared to the MgO.

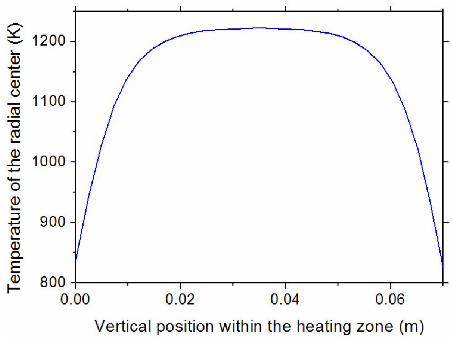

Fig. 5 Temperature along the radial center of the heating element

Figure 5 shows that the temperature along the radial center of the heating element varies a lot depending on the vertical position. Accordingly, temperatures of the fuels in actual irradiation test may change significantly in accordance with their vertical positions.

3. Summary

Thermal load simulation and verification experiments was carried out for an assessment of the design feasibility of irradiation rod, which will be used in an irradiation test of KAERI-developed TRISO fuels in 2012. COMSOL based FE heat transfer model built for the cases of the MgO and graphite heater. Results of the FE analysis showed quite a good agreement with those of the experiment for the case of MgO heater. The FE model should be improved for better accuracy to be utilized in the next study, which aims the optimization of the irradiation of the rod design.

Acknowledgement

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REFERENCES

[1] COMSOL AB., COMSOL Multiphysics Ver. 3.3.
[2] R. H. PERRY, D. GREEN, Perry's Chemical Engineers' Handbook, Sixth Ed., McGraw-Hill Book Co (1984).
[3]www.matweb.com/search/datasheet.aspx?MatGID=abc4415b0f8b490387e3c922237098da
[4]http://www.matweb.com/search/DataSheet.aspx?MatGUID=3f64b985402445c0a5af911135909344&ckck=1