Design of a Capsule for an Irradiation Test of TRISO Fuels in Compact Form

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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 fuel in compact form in the research reactor, HANARO in Korea for the evaluation and prediction of the irradiation behavior of the fuel.

A non-instrumented capsule for use in the irradiation test should be designed to provide a high temperature condition for the TRISO coated particle fuel held in the capsule and to withstand the thermal load imposed to the 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, an ABAQUS[1] based finite element model was developed to carry out a thermal analysis of a capsule for an irradiation test of the TRISO compact fuels in HANARO and the effects of design variables of the capsule on its thermal integrity were evaluated to determine appropriate dimensional design parameters of the capsule.

2. Methods and Results

2.1 Description of the Irradiation Test Capsule

The capsule has a cylindrical shape and mainly consists of the end plugs, external tubes, and specimens. The cross-sectional schematic view of the test capsule considered in this design study is shown in Fig. 1(a). Test fuels in their compact forms are located in the middle of the capsule. The encapsulating tubes are made of molybdenum, and the gaps are filled with neon gas. When the capsule is loaded into the reactor, it works as a heat source by a γ-ray irradiation. Temperature of the moderator surrounding the capsule is 40 °C.

The irradiation test capsule should provide a temperature circumstance as high as 950℃ to assure the actual core condition for the TRISO compact fuel. The tubes that encapsulate the test specimen should withstand the thermal load imposed to the metallic tubes as a result of the high temperature. The geometrical characteristics of the reactor core require the capsule diameter not to exceed 16mm.

2.2 Finite Element Analysis Model

A physics code, MCNP was used to calculate the heat generation rate due to a γ-ray irradiation. A User subroutine in FORTRAN for the ABAQUS solution was prepared to define the heat generations by the tubes and the compact fuels. The heat flux from the TRISO compact fuel was the sum of γ-heat from the matrix and the decay heat from the TRISO fuels retained in the compact.

Fig. 1(b) shows a 2-D finite element model for a thermal analysis of the test capsule. The elements are four-node linear heat transfer elements (DC2D4 in ABAQUS).

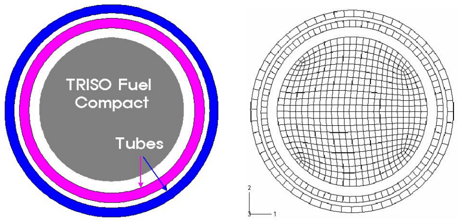

Fig.1. (a) Schematic view, (b) FE model of the Capsule

For a heat transfer analysis of the capsule, the gap conductance between the gaps and the convective heat transfer to the moderator as indicated in Fig. 2 should be considered. The gap conductance depends on the gap size, surface roughness, gas conductivity, surface temperatures, and the gas pressure. The coefficient for convective heat transfer to the moderator was obtained as a function the gas conductivity, the equivalent diameter, Re and Pr numbers [2].

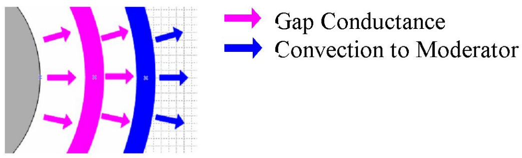

Fig.2. Heat transfer across the capsule

Density, thermal conductivity and specific heat of the molybdenum as functions of the temperature were found in Perry's Chemical Engineers' Handbook [3].

2.3 Parametric Study

Thermal sensitivities of the compact fuel and the inner tube were investigated as a function of the heat flux and the diameter of the compact fuel. The capsule has to provide a high temperature of 950℃ for the test compact fuels, and has to withstand the thermal load imposed by the high temperature caused by the fuel irradiation. In this study, the molybdenum tubes were assumed to withstand the thermal load at a temperature below 500℃.

The design variables considered in this parametric study, the heat flux and the diameter of the compact fuel were chosen as they had been proven critical in a previous design study which had been carried out with loose particles [4]. Fixed values of 0.5mm, 0.3mm and 8mm were used respectively for the tube thicknesses, the outer gap size, and the capsule diameter as they were considered appropriate in view of the capsule manufacturability and the reactor compatibility.

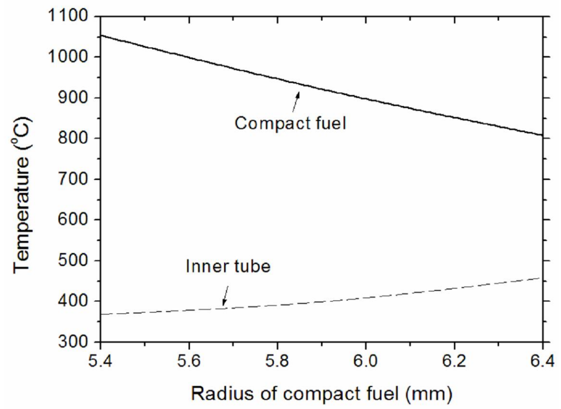

Fig. 3. Temperatures of the compact fuel and the inner tube as a function of the compact fuel diameter

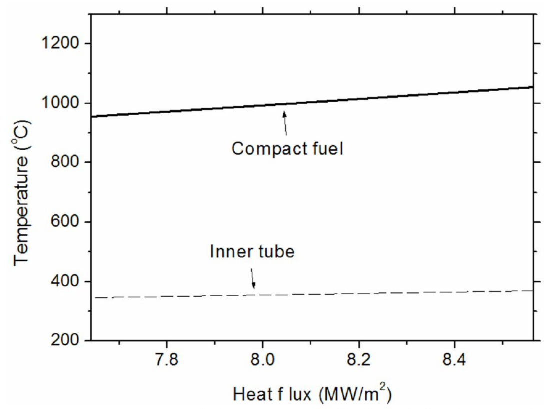

Fig. 4. Temperatures of the compact fuel and the inner tube as a function the fuel heat flux

Fig. 3 shows the temperatures of the inner tube and the compact fuel as a function of the compact fuel radius. The temperature of the compact fuel decreases as its radius increases because the decreased gap increases the conductance heat transfer across the gap. A temperature of 922℃ was obtained at the fuel radius of 5.9mm. The temperature of the inner tube decreases slightly as the compact fuel increases in radius. The temperature, however, is below the limit over the range of radius variation. Therefore, the temperature of the compact fuel can be decreased by decreasing its radius.

Fig. 4 shows the temperatures of the inner tube and the compact fuel as a function of the heat flux of the compact fuel. A smaller radius of 5.4mm was selected for the compact fuel in view of the results discussed regarding fig. 3. Both temperatures increase as the heat flux increases. At the heat flux of 7.64MW, the temperature of the compact fuel is 956℃ and the inner tube 345℃. Both temperatures are satisfactory in terms of the preset thermal requirements.

3. Conclusion

An ABAQUS[1] based finite element model was developed for a thermal analysis of an irradiation test capsule. The effects of design variables of the capsule on its thermal integrity were evaluated to determine appropriate cross-sectional dimensions of the capsule.

The results showed that a capsule with a compact fuel with the radius of 5.4mm and the heat flux of 7.64MW is most desirable in terms of the thermal integrity of the capsule. A heat flux of 7.64MW can be obtained from a compact fuel with 21 TRISO particle fuels. The capsule with this design assured a temperature of 956℃ for the compact fuel. The temperature of the inner tube was 345℃.

Acknowledgement

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