A Thermal Analysis of a TRISO-coated Fuel Particle

Kim Young Min, D.H. Kim, Y.Y. Yang, and J.H. Chang
Korea Atomic Energy Research Institute
P.O. Box 105, Yuseong-gu, Daejeon, 305-600, Republic of Korea
E-mail: nymkim@kaeri.re.kr

1. Introduction

A TRISO-coated fuel particle is a basic element of HTGR fuel. The integrity of the particle should be assured during life. For that reason, many thermal and mechanical analyses of a TRISO-coated fuel particle have been performed [1,2]. It is very important to calculate the temperature gradient within an individual particle in order to analyze the thermal effects such as a thermal stress or a kernel migration. The study shows the temperature distribution within the kernel, buffer, and three coating layers of a TRISO-coated fuel particle through a rigorous numerical calculation, and compares the results with ones from a simple analytical solution [2].

2. Modeling for a Thermal Analysis

The TRISO-coated fuel particle consists of a fuel kernel, a buffer layer, an inner pyrocarbon (IPyC) layer, a silicon carbide (SiC) layer, and an outer pyrocarbon (OPyC) layer as in Fig. 1.

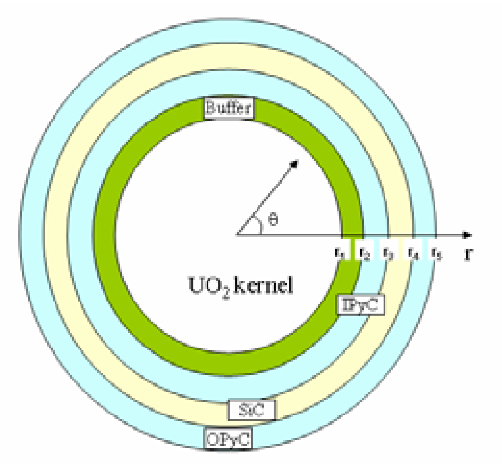
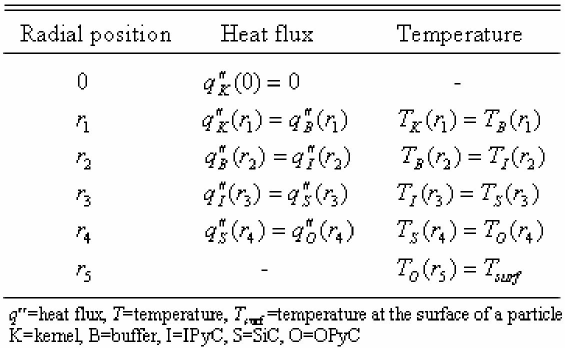


Fig. 1 A TRISO-coated fuel particle

A numerical modeling for calculating the temperature distribution within the TRISO-coated fuel particle was set up by an implicit point-scheme finite difference method [3]. The temperature is assumed to be symmetric about the particle center. The kernel is divided into N intervals in the radial direction on the basis of an equal volume of shell. The buffer and the coating layers are divided into two intervals, respectively. The boundary conditions for the thermal analysis are given in Table 1. The temperature at the surface of the particle must be calculated in the other analysis, which is used to calculate the temperature distribution in a fuel element like a fuel compact or a pebble.

Table 1 Boundary Conditions for a Thermal Analysis



Radial position	Heat flux	Temperature
0	$q''_K(0) = 0$	-
r_1	$q''_K(r_1) = q''_B(r_1)$	$T_K(r_1) = T_B(r_1)$
r_2	$q''_B(r_2) = q''_I(r_2)$	$T_B(r_2) = T_I(r_2)$
r_3	$q''_I(r_3) = q''_S(r_3)$	$T_I(r_3) = T_S(r_3)$
r_4	$q''_S(r_4) = q''_O(r_4)$	$T_S(r_4) = T_O(r_4)$
r_5	-	$T_O(r_5) = T_{surf}$

q''=heat flux, T=temperature, T_{surf}=temperature at the surface of a particle
K=kernel, B=buffer, I=IPyC, S=SiC, O=OPyC

The temperature increments at any time or fluence can be obtained by solving the following system of equations resulting from the finite difference method.

$$[M]^{(m-1)}\{\Delta T\}^{(m)} = \{R\}^{(m-1)} - [M]^{(m-1)}\{T\}^{(m-1)},$$

where the superscript m means an iteration step, the matrix $[M]$ consists of tri-diagonal elements.

3. Calculational Results

The TRISO-coated fuel particle for NHDD-T1 was selected. The kernel diameter is 700 μm and the buffer thickness is 65 μm. The thickness of the IPyC, SiC, and OPyC coating layers are 30, 25, and 30 μm, respectively. The temperature at the surface of the particle is assumed to be 475 and 1200 ℃. The heat generation rate in the kernel of the particle is assumed to be between 682 and 6820 MW/m^3.

Fig. 2 shows the temperature distribution within the TRISO-coated fuel particle when the surface temperature of the particle is 475 ℃ and the heat generation rate in the kernel of the particle is 682 MW/m^3. Fig. 3 represents the temperature distribution when the surface temperature is 1200 ℃ and the heat generation rate in the kernel is 682 MW/m^3. In both cases, a simple analytical solution tends to underestimate the temperature distribution in the particle as compared to the finite difference solution although the differences are not significant.

Fig. 4 shows the temperature distribution within the fuel particle when the surface temperature of the particle is 1200 ℃ and the heat generation rates in the kernel of the particle are 682 and 6820 MW/m^3. The temperature and the temperature gradient in the kernel and the buffer increase with the power density. It cannot, however, be said that the temperature and the temperature gradient in the three coating layers greatly increase with the power density.

In Fig. 2~4, the temperature of the coating layers does not depend on the power densities, but greatly on the temperature of the outer surface of the particle.

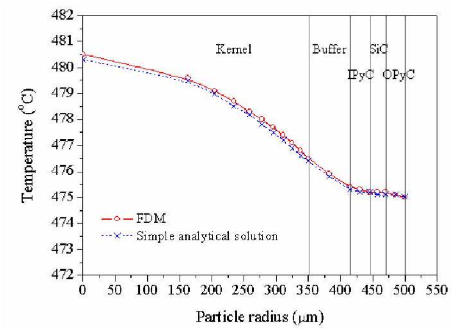


Fig. 2 Temperature distribution within a TRISO-coated fuel particle (T$_{surf}$ = 475℃, $q_K''' = 682\, MW/m^3$)

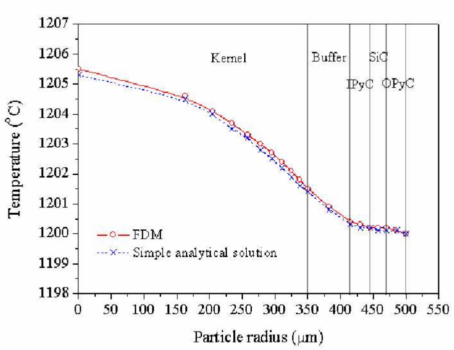


Fig. 3 Temperature distribution within a TRISO-coated fuel particle (T$_{surf}$= 1200℃, $q_K''' = 682\, MW/m^3$)

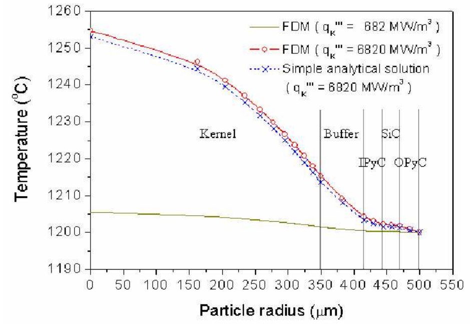


Fig. 4 Temperature distribution within a TRISO-coated fuel particle (T$_{surf}$= 1200℃)

4. Conclusion

From the thermal analysis of a TRISO-coated fuel particle, the following conclusions are made:

1. A simple analytical solution underestimates the temperature distribution in the particle as compared to the rigorous numerical solution, although the difference is not significant.
2. In both normal and severe power conditions, the temperature gradients across the three coating layers are very small, which means that there is only a little thermal stress difference across each layer.
3. The temperature of the coating layers does not depend on the power conditions, but greatly on the temperature of the outer surface of the particle.

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