A Modeling on Gas Pressure Buildup within a Coated Fuel Particle

Kim Young Min*, Y. K. Kim, S. C. Oh, K. C. Jeong, W. K. Kim, Y. W. Lee and M. S. Cho
Nuclear Hydrogen Reactor Technology Development Division, Korea Atomic Energy Research Institute
P.O. Box 105, Yuseong-gu, Daejeon, 305-600, Republic of Korea
**Corresponding author: nymkim@kaeri.re.kr*

1. Introduction

The HTGR (High Temperature Gas-cooled Reactor) fuel uses a TRISO-coated fuel particle (CFP) which consists of a kernel, low-density pyrocarbon as a buffer, inner high-density pyrocarbon, silicon carbide, and outer high-density pyrocarbon. The kernel produces free oxygen and various toxic fission gases during the heat generation through the fission of nuclear materials in it. CO gas is generated through the interaction of the free oxygen with carbon atoms of the inner region of the coating layers. The CO and fission gases gather in the void volume in the kernel and buffer of an intact TRISO CFP and cause pressure buildup in the volume. The pressure buildup should be estimated since it is one of factors deteriorating CFP integrity. This study describes the physico-chemical models for the calculation of the gas pressure buildup in the void volume in a CFP.

2. Physico-chemical Models for Gas Pressure Caculation

The void volume in a CFP are the volume of open pores in a kernel and a buffer. The kernel swells due to gaseous and solid fission products. The buffer becomes dense when the kernel swells and pushes the buffer outwards. The denser it becomes, the stronger the buffer. It is guessed that there is a critical point where the buffer densification becomes saturated, then the kernel swelling becomes limited.

The free oxygen atoms are liberated by fission in a kernel. They interact with the carbon atoms of the inner coating layers, and the CO gas forms. The production of free oxygen depends on the nature of the fuel and on the type of fissile material. It has been proven that unlike UO_2, fuels containing carbon do not produce excess free oxygen. Some oxygen release models were developed by Homan [1] and Proksch [2].

The fission gases are xenon and krypton isotopes. The fractional release of the fission gases generated in the kernel into the buffer during irradiation is given in Ref. [3]

The classical ideal gas law and the Redlich-Kwong equation of state have been traditionally used to calculate the internal pressure within a CFP [4].

3. Calculation Results

Table 1 gives the thicknesses and densities of layers in a CFP. Table 2 gives the data for gas pressure calculations. Fig. 1 shows the variation of void volume with burnup. In this calculation, only solid swelling was considered which was assumed to be initiated at the burnup of 6000 MWd/tHM. In Fig. 1, the void volume starts to decrease at the burnup of 6000 MWd/tHM. Fig. 2 presents the generation of the gas pressure in the void volume. It shows that CO pressure is higher than the fission gas pressure throughout the irradiation.

Table 1 Thicknesses and Densities of Layers in a Coated Fuel Particle

Layers	Thickness (μm)	Density (g/cm^3)
OPyC	40	1.90
SiC	35	3.20
IPyC	40	1.90
Buffer	100	0.95
Kernel	500*	10.8

* Diameter.

Table 2 Data for Gas Pressure Calculations

Parameters	Values
Kernel material	UO_2, 8 wt%
Open porosity fraction of kernel	1
Open porosity fraction of buffer	1
Fraction of buffer thickness which becomes dense at maximum	0.1
Solid swelling rate, tHM/MWd	6×10^{-7} > 6000 MWd/tHM
Gaseous swelling rate, tHM/MWd	0
Fission gas diffusivity, m^2/s	$8.8\times10^{-15}e^{-54000/RT} + 6.0\times10^{-1}e^{-480000/RT}$ where R = 8.3144 J/(mol K), T=temperature (K)
Fission yield	0.017 for Kr, 0.244 for Xe

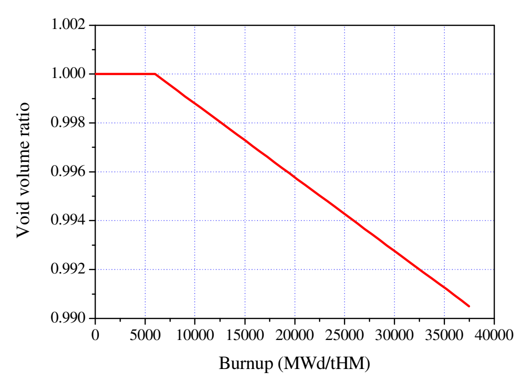

Fig. 1 Variation of Void Volume with Burnup

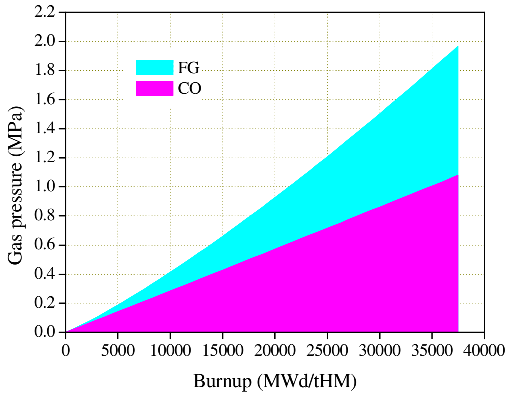

Fig. 2 Variation of Gas Pressure with Burnup

4. Summary

Various physico-chemical models have been described for the calculation of the gas pressure in the void volume of a CFP. The models treat the void volume change, the oxygen release from a kernel, the fission gas release from a kernel, and the equations of state of a gas. Some test calculation results depict, appropriately, the change in the void volume and the gas pressure buildup with burnup.

REFERENCES

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