CO Gas Generation in a Layered UCO Kernel of an HTR Coated Fuel Particle

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1. Introduction

UCO is one of kernel materials of a coated fuel particle of a high temperature reactor (HTR). The UCO kernel is a mixed UO_2, UC and UC_2 for a reduced CO pressure. The image analyses of UCO kernels show that the fabricated UCO kernels have an inner mixed oxide and carbide region, a UO_2-rich rind, and a thin outer UC_z skin [1,2]. It is expected that a significant number of free oxygens generated in the UO_2 rind region pass quickly through the very thin UO_z skin, and they combine with buffer carbon.

All of free oxygen generated in a homogeneous UCO kernel are consumed to combine with carbon and fission product in the kernel. It is necessary to check how much CO gas is generated in a layered UCO kernel due to the UO_2 region. This study calculates the CO gas generations according to the size of the UO_2 rind region, and evaluates the potential to compromise the integrity of a coated fuel particle.

2. Characteristics of a layered UCO kernel

Fig.1 shows a layered UCO kernel [2]. UC_z is a mixture of UC and UC_2. The kernel radius is 212.5 μm, and the thickness of UC_z skin is 6.3 μm. It is assumed that the composition of the innermost UO_2+UC_z region is maintained exactly as it is in a homogeneous UCO kernel. The homogeneous UCO kernel material is $UC_{0.4}O_{1.5}$ and the density is 10.4 g/cm^3.

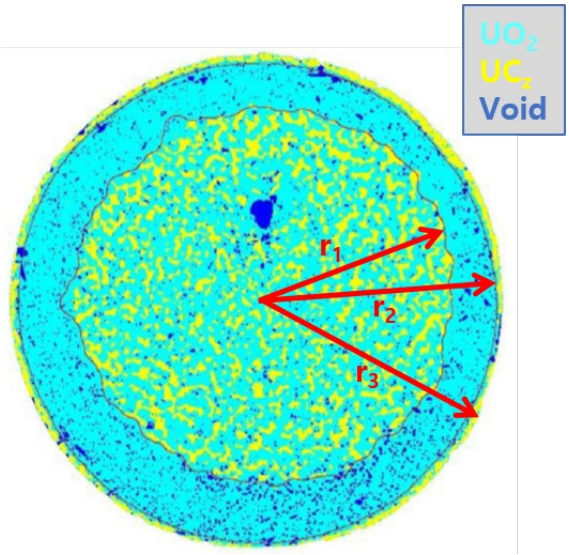


Fig. 1. A layered UCO kernel.

3. Calculation of CO gas in a layered UCO kernel

A reference HTR operates normally for 1300 days. For evaluation, the thickness of the UO_2 rind region was selected as 5, 10, 15, 20 μm. Table I shows the number of moles of UO_2, UC, UC_2 in the three regions. Fig. 2 shows the temperature evolution during normal operation of the reference HTR and the number of fissions according to the UO_2 rind thickness.

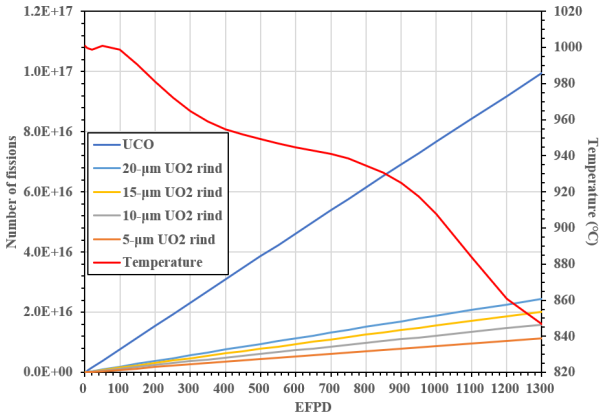


Fig. 2. Evolution of temperature and fission according to the UO_2 rind thickness.

Ref. [3] provides a mathematical expression for a numerical calculation of oxygen atom per fission (OPF) for UO_2 kernel:

$$OPF^{(n)} = OPF^{(n-1)} + g\left(\bar{T}^{(n)}\right)\left[t^{(n)} - \bar{t}^{(n)}\right] \cdot \Delta t^{(n)}, \quad (1)$$

where (n) is a time step (n=1,2,3,···), $g(T) = 1.66353 \times 10^{-10} e^{-\frac{162730.4}{RT}}$, R is a gas constant (8.314 J/(mol K)), T is a temperature (K), t is a time (s), $\bar{T}^{(n)} = 0.5\left(T^{(n)} + T^{(n-1)}\right)$ (K), $\bar{t}^{(n)} = 0.5\left(t^{(n)} + t^{(n-1)}\right)$ (s), $\Delta t^{(n)} = t^{(n)} - t^{(n-1)}$(s). The allowable maximum OPF is 0.625.

4. Calculation Results

Fig. 3 and 4 show the evolution of CO gas pressure according to temperature in the 5-μm and 20-μm UO_2 rind regions, respectively. Fig. 5 shows CO gas pressure at 1300 day according to temperature in each UO_2 rind region. The CO gas pressure increase with temperature and the thickness of UO_2 rind. Even in the thickest 20-μm UO_2 rind region, the end-of-life CO gas pressure is

about 1.3 MPa. Such small gas pressure does not affect the pressure vessel failure of coating layers of a coated fuel particle.

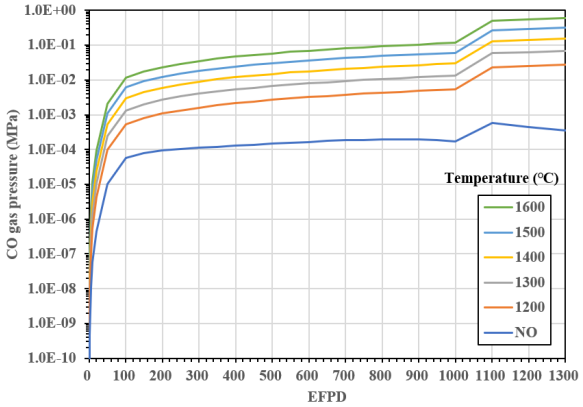


Fig. 3. Evolution of CO gas pressure in 5-μm UO_2 rind.

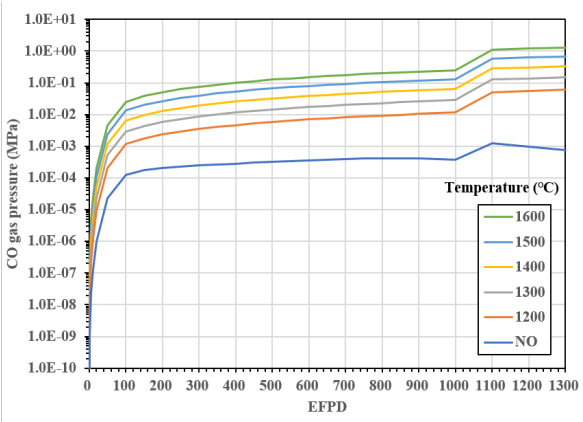


Fig. 4. Evolution of CO gas pressure in 5-μm UO_2 rind.

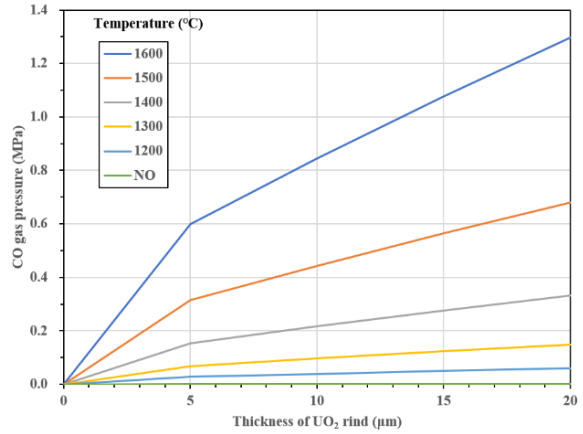


Fig. 5. CO gas pressure at 1300 day according to temperature.

5. Summary

The CO gas pressure was evaluated in a layered UCO kernel according to the temperature and UO_2-region size. The CO gas pressure increases with temperature and UO_2-region thickness. In the thickest 20-μm UO_2 rind region, the end-of-life CO gas pressure is only about 1.3 MPa. At thickness of UO_2 region of 20 μm or less and temperature of 1600 ℃ or less, additional CO gas pressure does not affect the mechanical failure of coating layers of a coated fuel particle.

ACKNOWLEDGEMENTS

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Table I: Amount of UO_2, UC_2, UC in a layered UCO kernel

UO_2 rind thickness (μm)	Mole in UO_2+UC_z region			Mole in UO_2 rind	Mole in UC_z skin	
	UO_2	UC_2	UC	UO_2	UC_2	UC
0	1.17695×10^{-6}	2.35390×10^{-7}	1.56927×10^{-7}	0	0	0
5	9.99000×10^{-7}	1.99800×10^{-7}	1.33200×10^{-7}	1.77951×10^{-7}	3.55902×10^{-8}	2.37268×10^{-8}
10	9.26357×10^{-7}	1.85271×10^{-7}	1.23514×10^{-7}	2.50593×10^{-7}	5.01187×10^{-8}	3.34125×10^{-8}
15	8.57324×10^{-7}	1.71465×10^{-7}	1.14310×10^{-7}	3.19626×10^{-7}	6.39253×10^{-8}	4.26168×10^{-8}
20	7.91809×10^{-7}	1.58362×10^{-7}	1.05575×10^{-7}	3.85142×10^{-7}	7.70283×10^{-8}	5.13522×10^{-8}