The Fuel Performance Analysis of LWR Fuel containing High Thermal Conductivity Reinforcements

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1. Introduction

Light Water Reactors (LWR) use uranium oxide, UO_2, as a nuclear fuel because it has a high melting point, good fabricability and excellent irradiation stability. Despite such advantages, it shows a low thermal conductivity ranging from 2 to 8 W/m-K at reactor operating temperatures [1]. There have been many efforts to increase the thermal conductivity of uranium oxide fuel by addition of high thermal conductivity compounds such as BeO or SiC [2,3]. BeO or SiC could be chosen as reinforcement materials for enhancement of the thermal conductivity of UO_2 because they have been found to be compatible with UO_2 when sintered at high temperatures. The thermal conductivity of fuel affects many performance parameters including the fuel centerline temperature, fission gas release and internal pressure. In addition, enhanced safety margin of fuel might be expected when the thermal conductivity of fuel is improved by the addition of high thermal conductivity reinforcements. Therefore, the effects of thermal conductivity enhancement on the fuel performance of reinforced UO_2 fuel with high thermal conductivity compounds should be analyzed. In this study, we analyzed the fuel performance of modified UO_2 fuel with high thermal conductivity reinforcements by using the FRAPCON-3.5 code [4]. The fissile density and mechanical properties of the modified fuel are considered the same with the standard UO_2 fuel.

2. Modeling of Thermal Conductivity

The composite thermal conductivity can be calculated using the Maxwell-Eucken equation [5],

$$K = K_m \frac{(2-2V_r)K_m + (1+2V_r)K_r}{(2+V_r)K_m + (1-V_r)K_r} \qquad (1)$$

where K, K_m and K_r are the thermal conductivity for the composite, matrix and the reinforcement; V_r is the volume fraction of the reinforcement. Table 1 shows the thermal conductivities of UO_2, BeO and SiC at room temperature and high temperatures. In order to obtain the thermal conductivity enhancement factors, the values for K/K_m for 10-30 vol% BeO added UO_2 fuel were calculated representatively as shown in Table 2. The enhancement factors range from 1.22 to 1.78 at 1500°C when the addition of BeO is assumed to be from 10vol.% to 30 vol.%. Because the average thermal conductivity enhancement factors from 1000°C to 2000°C are not changed significantly, the factors at 1500°C were used for the fuel performance calculation of modified UO_2 fuel.

Table 1. The thermal conductivities of UO_2, BeO, SiC [6,7].

Material	UO_2	BeO	SiC
R.T.	7.47W/mK	260W/mK	150W/mK
1000°C	2.78W/mK	25.0W/mK	65W/mK
1500°C	2.2W/mK	16.7W/mK	57 W/mK
2000°C	1.82W/mK	12.5WmK	48 W/mK

Table 2. Thermal conductivity enhancement factors of 10-30 vol% BeO added UO_2.(K/Km)

Material	BeO 10Vol.%	BeO 20Vol.%	BeO 30Vol.%
R.T.	1.30	1.68	2.14
1000°C	1.24	1.51	1.84
1500°C	1.22	1.48	1.78
2000°C	1.21	1.46	1.74

3. Results

The fuel performance of standard UO_2 and modified UO_2 having various volume fractions of BeO were analyzed by FRAPCON-3.5. As a power history to investigate the effects of the thermal conductivity of fuel pellets, the power history of IFA-429DH from Halden HBWR was used as shown in Fig. 1.

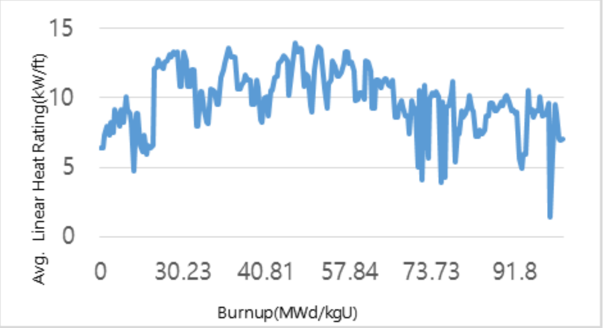

Fig.1. A power history of IFA-429DH (Halden HBWR)

The centerline temperatures of UO_2 and modified UO_2 fuels with 10-30 vol% BeO are shown in Fig. 2. The modified fuel with a higher volume fraction of BeO showed the lower centerline temperatures with burnup. Fig. 3 presents the average fission gas release values of UO_2 and modified UO_2 fuels with 10-30 vol% BeO. After 40 MWd/kgU, the average fission gas release increased significantly for the standard UO_2 fuel for the power history of IFA-429DH. The reduced fission gas release values of 10-30vol% BeO added fuel are attributed to the lower centerline temperatures. In addition, reduced internal pressure values are expected owing to the reduced fission gas release for the modified fuel with high thermal conductivity reinforcements.

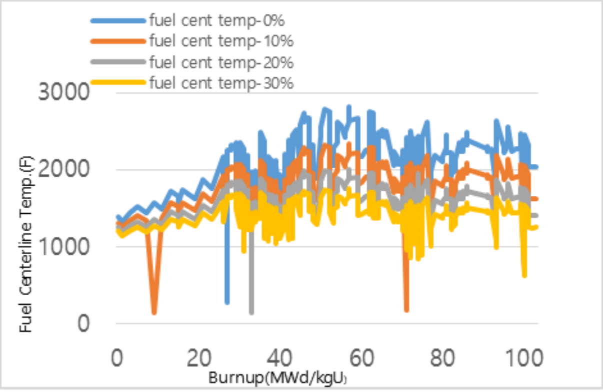

Fig.2. Fuel Centerline temperatures of UO_2 and modified UO_2 fuels with 10-30 vol% BeO

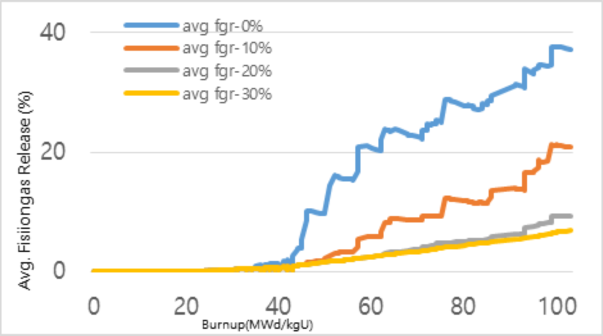

Fig.3 Average fission gas release values of UO_2 and modified UO_2 fuels with 10-30 vol% BeO

However, the effects of the neutron absorption, fissile element density, mechanical properties should be analyzed further to investigate the comprehensive impact on the fuel performance of the BeO or SiC added UO_2 fuel. Because the possible degradation of the thermal conductivity of BeO or SiC was not considered in this study, the temperature differences of normal UO_2 and modified UO_2 fuels might be overestimated. In addition, the fission gas release behavior of the modified UO_2 fuels might deviate from the behavior of normal UO_2 fuel. Further study on the effects of microstructures on the fission gas release behavior is required.

Conclusions

The fuel performance of modified UO_2 with high thermal conductivity reinforcements were analyzed by using the FRAPCON-3.5 code. The thermal conductivity enhancement factors of the modified fuels were obtained from the Maxwell model considering the volume fraction of reinforcements. The fuel performance evaluation results showed notable improvements in important performances such as fuel centerline temperature and fission gas release.

5. REFERENCES

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