Modification of UO_2 fuel thermal conductivity model at high burnup structure

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Abstract

The thermal conductivity of UO_2 under in-pile irradiation changes due to produced porosity. This paper has calculated evolution of fuel swelling and porosity by using a model of fuel swelling due to fission gases that is valid for range of low temperature and burnups up to 120 MWd/KgU where high burnup structure (HBS) is formed. The HALDEN thermal conductivity correlation is selected for study of the fuel swelling and porosity evolution effect on irradiated UO_2 thermal conductivity. In addition, the correlation is completed with a proposed porosity factor. With considering porosity evolution by burnup, is seen a reduction about 25% in the thermal conductivity which increases the fuel temperature. Calculation results indicate a good agreement with experimental data.

Key word: Thermal conductivity, Fuel swelling, Porosity, High burnup structure

Introduction

The UO_2 fuel thermal conductivity is affected by many factors such as temperature, porosity, fission products, changing in fuel microstructure and creation of high burnup structure, stoichiometry and irradiation damage. However, determination of porosity impact on thermal conductivity is more complicated than other factors. The large grains convert to smaller so atoms absorption takes place more on the grain boundary and as a result, large grain boundary bubbles will be generated which have significant contribution to the production of swelling due to the gas bubble and porosity [3-1].

Various equations, both empirical and analytical have been developed to describe the effect of porosity on the thermal conductivity. Taking a unit cell of porous material represented as a cube of the solid material surrounding a gas pore, Loab [4] and Kampf et al. [5] derived an analytical expression for the porosity effect on thermal conductivity. Then, DART code [6] applies their model sequentially for modelling of dispersion fuel thermal conductivity. Studies on thermal conductivity, Spino et al. [9] obtained a relation for total swelling, which is related to the fuel bulk density and porosity. By calculating the total swelling and measuring the bulk fuel density, the porosity evolution in irradiated UO2 with burn-up was demonstrated that was included of volume porosity (cavity). In our previous work [10] an expression was derived for total volume porosity of the fuel that was consist of two parts: volume porosity and swelling porosity. In this paper, we try to determine quantitatively the porosity effect on thermal conductivity of UO_2 fuel with using the HALDEN thermal conductivity correlation [11].

Models and methods

❑ Swelling and porosity

Rest method [3,9] is used for calculation of swelling evolution in low temperature regime at low and high burnups. Porosity evaluation , P, can be calculated after calculation of total fuel swelling . P is included [10,12]: $P = P_s + P_v$

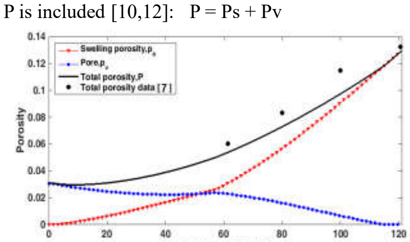


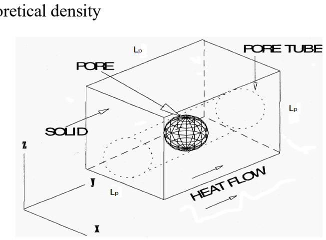
Fig. 1. Formation of pore P_v, swelling porosity P_s, and total porosity P as a function of burnup at 800K in addition total porosity data [7].

❑ Halden thermal conductivity

$$k_{95} = \frac{1}{0.1148 + 0.0035Bu + (0.0002474 - 8.24\times10^{-7}Bu)(T-273)} + 0.0132\, e^{0.00188(T-273)} \quad (1)$$

K_{95} (W/mK) UO_2 Thermal conductivity at 95% theoretical density
Bu (MWd/KgU) Burnup
T (K) Temprature

❑ Porosity evolution



$$\frac{k_e^V}{k_0} = 1 - \left[\pi\left(\frac{3}{4\pi}P_V\right)^{\frac{2}{3}}\right]\left[1 - \frac{k_g}{2k_0\left(\frac{3}{4\pi}P_V\right)^{\frac{1}{3}}}\right] \quad (2)$$

$$\kappa_P = \frac{k_{eff}}{k_0} = \left[1 - \pi\left(\frac{3}{4\pi}P_V\right)^{\frac{2}{3}}\right]\left\{1 - \left[\pi\left(\frac{3}{4\pi}P_s\right)^{\frac{2}{3}}\right]\left[1 - \frac{k_g}{2k_e^V\left(\frac{3}{4\pi}P_s\right)^{\frac{1}{3}}}\right]\right\} \quad (3)$$

❑ Porosity factor

Fig. 2 shows the porosity factor obtained in this article that is compared with several porosity factor [14,15].

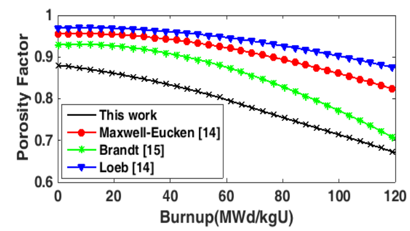


Fig.2. Comparing the proposed porosity factor in Eq. (3) with others at 800K.

❑ Thermal conductivity

Fig.3compares the evolution of calculated UO_2 thermal conductivity based on the HALDEN correlation as a function of local burn-up for two cases, including a constant volume porosity 3% and an evolving one as given above. Fig.4shows the UO_2 thermal conductivity calculated by the HALDEN correlation as a function of the temperature for different burn-ups while the computed porosity evolution in the porosity factor is taken into account.

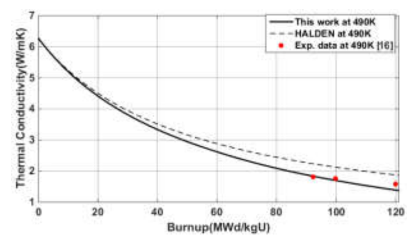


Fig. 3. Calculated UO2 fuel thermal conductivity based on HALDEN correlation vs. burn-up at 490K with porosity evolution included in comparison with the case with constant porosity and experimental data [16].

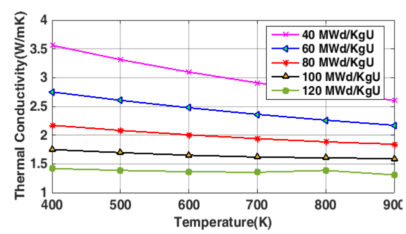


Fig. 4. Calculated UO_2 Thermal conductivity as a function of temperature for different burn-ups.

Conclusion

In this paper the volume porosity evolution of irradiated UO_2 fuel with burn-up previously estimated using the Rest's gaseous swelling model with progressive recrystallization was used to study the degradation of irradiated UO_2 thermal conductivity with burn-up. To do that, the thermal conductivity of and HALDEN correlation was selected. Then we combined it (as a Coefficient) with a porosity factor developed on the basis of three-phase type morphology of irradiated fuel. A decrease in the UO_2 thermal conductivity up to 25% at local burn-up levels around 120MWd/kgU compared to the case with as-fabricated porosity during of the irradiation time, was shown. A very good agreement was seen from the comparison of predicted thermal conductivity with the available experimental data at high burn-ups.

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