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Numerical Investigation of Thermal Conductivity in UO_2-5 vol% Mo Fuel Pellet with Mo Configuration of Radial Direction

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1. Introduction

To enhance the safety of light water reactor, many studies of Accident-Tolerant Fuels (ATFs) have being developed [1]. The ceramic UO_2 fuel pellet with low thermal conductivity occurred high temperature gradient and reduce the structure stability of fuel pellet. One method to mitigate the temperature gradient of the pellets is by adding a highly conductive material [2]. In terms of improving thermal conductivity, the continuous networks of additives were better than dispersed [3]. Moreover, thermal conductivity could be more enhanced when the additives was arranged to main heat flow direction [4]. In this study, we designed the UO_2 – 5 vol% Mo fuel pellet with Mo layer placed on top and bottom of UO_2 part in order to improve heat transfer in the radial direction. The thermal conductivity of UO_2 – 5 vol% Mo pellets with Mo layer on top and bottom surface of UO_2 part was numerically investigated, compared to the UO_2 pellets. As the pellet height decrease, the effective thermal conductivity of this composite pellet was increased and the central maximum temperature was reduced.

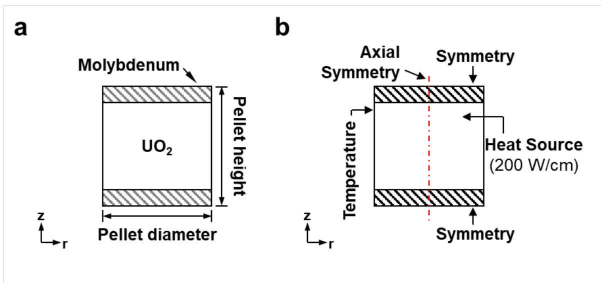

Figure 1. UO_2 – 5 vol% Mo fuel pellet with top and bottom configuration of Mo layer. (a) Schematic to show geometrical configuration. (b) Thermal boundary conditions for numerical calculations.

2. Simulation model

In order to thermal conductivities and temperature distribution of the pellets, the 2-D axial model was fabricated as shown in Figure 1. The content of Mo was fixed as 5 vol% and the Mo layer was placed on the top and bottom of UO_2 part (Figure 1a). Under constant pellet diameter, the numerical calculation was conducted according to the pellet height. The thermal boundary conditions of the 2D axial symmetry model (Figure 1b) were follows: (1) the pellet centerline in z axis was set an axial symmetric condition, (2) constant temperature to the outer side of the pellet, (3) symmetric conditions to the top and bottom sides, and (4) uniform heat generation of 200W/cm in UO_2 region. The numerical calculation was conducted to steady-state condition. The material properties were adopted for UO_2 form MATPRO [5], and J.K. Fink [6], for Mo form S.I. Abu-Eishah [7].

3. Result and discussion

3.1 Thermal conductivities in terms of pellet height

The geometric effects on thermal conductivity at 1200℃ in terms of the pellet height from 9 to 4.5 mm were investigated (Figure 2). Although in the UO_2 pellet, thermal conductivity was constant in spite of pellet height change, in UO_2 – 5 vol% Mo pellet with Mo layer placed on top and bottom surface of UO_2 part, it was increased as the pellet height decreased at the same Mo content. It was reason that the lateral thermal resistance from mid-plane to Mo layers of the main heat flow direction was reduced as the pellet height decrease. As a result, the effective thermal conductivity at 1200 °C of UO_2 – 5 vol% Mo pellet with top and bottom Mo configuration significantly was increased, compared to UO_2 pellet to 80% at pellet height of 4.5 mm.

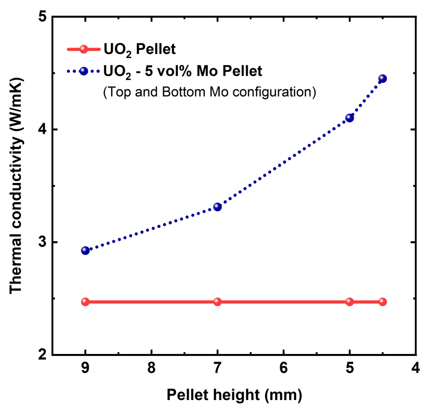

Figure 2. Comparison of thermal conductivities of UO_2 pellet and UO_2 – 5 vol% Mo fuel pellet in terms of pellet height at temperature of 1200˚C.

3.2 Effect of the pellet height on maximum temperature

We further investigated the maximum temperature of UO_2 – 5 vol% Mo fuel pellets with top and bottom Mo configuration as shown in Figure 3. The radial surface temperature of pellets was set as 440℃. In the pellet height of 9.0 mm, the maximum temperature was reduced by 9% in UO_2 – 5 vol% Mo fuel pellets with top and bottom Mo layer, compared to UO_2 pellet. Moreover, in the pellet height of 4.5 mm, the core temperature significantly lower of 25% compared to UO_2 pellet. Importantly, UO_2 – 5 vol% Mo fuel pellets with the radial direction configuration of Mo layers, were able to achieve high thermal conductivity by considering arrangements of highly thermal conductive additives to main heat flow direction. As a result, the temperature gradient could be effectively reduced as pellet height decreased.

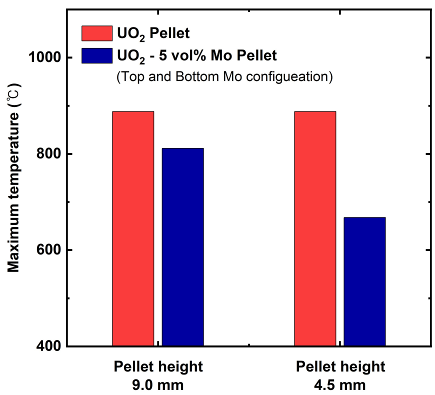

Figure 3. Comparison of maximum temperature between UO_2 pellet and UO_2 – 5 vol% Mo fuel pellet with top and bottom Mo layer with pellet height of 9.0 mm and 4.5 mm.

4. Conclusion

The thermal conductivities and maximum temperatures of UO_2 – 5 vol% Mo fuel pellets with Mo layer placed on top and bottom surface of UO_2 part were numerically investigated according to pellet height compare to UO_2 pellet. Through the top and bottom configuration of Mo layer on UO_2 part, thermal conductivities could be effectively enhanced by reducing pellet height. As a result, the remarkable enhancements of effective thermal conductivities of the UO_2 – 5 vol% Mo pellet at height 4.5 mm are contributed to reducing their maximum temperature of 25% compare to UO_2 pellet.

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