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Assessment of model uncertainty for effective thermal conductivity of the SPACE in crumbled fuel

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1. Introduction

Under Loss of Coolant Accident (LOCA) conditions, clad ballooning can occur due to internal overpressure and fuel rods can be overheated and undergo a complex process known as fuel fragmentation, relocation, and dispersal (FFRD) [1] according to different fuel burnup. The models [2] for FFRD phenomena implemented to the SPACE to take into account the effect of mass relocation on heat generation and thermal conductivity degradation during the LOCAs as mentioned in the previous studies [3-4]. In the previous study [4], the model for an effective thermal conductivity of crumbled fuel described and implemented into the SPACE. And it is verified as the SPACE calculation results compared with the analytic solutions for the simple conceptual problem.

The purpose of this study is to assess the model uncertainty for effective thermal conductivity by comparing the experimental data for measured effective thermal conductivity of uranium oxide powder in the gases.

2. Methods and Results

In this section, the model for an effective thermal conductivity of crumbled fuel is described. The model accuracy is demonstrated by comparing the calculated results of the model with the measured data for effective thermal conductivity of uranium oxide powder in the various gases.

2.1 Effective thermal conductivity of crumbled fuel

For crumbled fuel pellets in ballooned clad, it is difficult to define the properties of particles and the particle bed due to the irregularities of crumbled fuel particles. Various models have been proposed for calculating the effective thermal conductivity of particle beds, in which the particles are well defined. Therefore, we have to rely on simple models. In this study, the correlation proposed by Chiew and Glandt [5] was selected to determine the effective thermal conductivity of crumbled fuel. This correlation consists of the thermal conductivities of fuel fragmentation (λ_f) and the surrounding gas (λ_g), and packing fraction (ϕ) of the fuel particles. The correlation is

$$\frac{\lambda_{eff}}{\lambda_f} = \frac{(1-\beta)}{(1+2\beta)(1-\beta\phi)}\left(1+2\beta\phi+\left(K_2-3\beta^2\right)\phi^2\right) \qquad (1)$$

Here, β is the reduced thermal polarizability and define in eq. (2).

$$\beta = \frac{\lambda_f - \lambda_g}{\lambda_f + 2\lambda_g} \qquad (2)$$

$\lambda_{eff} / \lambda_f$ is the ratio of the effective thermal conductivity to the conductivity of fuel, and K_2 is a function of the reduced thermal polarizability and packing fraction. Chiew and Glandt approximated the function K_2 in eq. (3) and found the best fit to tabulated values as eq. (4) ~ (5).

$$K_2(\beta,\phi) \approx K_2^{(0)}(\beta) + K_2^{(1)}\phi \qquad (3)$$

$$K_2^{(0)}(\beta) = 1.7383\beta^3 + 2.8796\beta^2 - 0.11604\beta \qquad (4)$$

$$K_2^{(1)}(\beta) = 2.8341\beta^3 - 0.13455\beta^2 - 0.27858\beta \qquad (5)$$

2.2 Assessment of model uncertainty

To check the model accuracy for an effective thermal conductivity of crumbled fuel, some experimental data are available for the effective thermal conductivity of UO_2 powders in various gases and mixture gases [6]. The powders used in these experiments were of unirradiated UO_2 and had a mean particle size of about 85 um. The experiments were conducted between 200 and 1500 °F in an atmosphere of various gases. The void fraction occupied by the gas was 0.405 in all runs.

Fig 1 is a comparison of measured data for the effective thermal conductivity at approximately 850 K with results calculated through eq. (1)~(5). In the calculations, the thermal conductivity of UO_2 was acquired from the internal thermal property functions of the SPACE at each temperature and the ones of gases (He & He/Ar mixtures) was taken from reference data [6]. The numbers 1.857 and 0.333 indicate the ratios of helium and argon in the gas mixtures in Fig 1.

Fig 2 shows comparison for effective thermal conductivity between calculated data and measured data. It is clear from Fig. 1&2 that the correlation by Chiew and Glandt reproduces the experimental data quite well. The predicted values of thermal conductivity using this model are bounded within 25% of uncertainty.

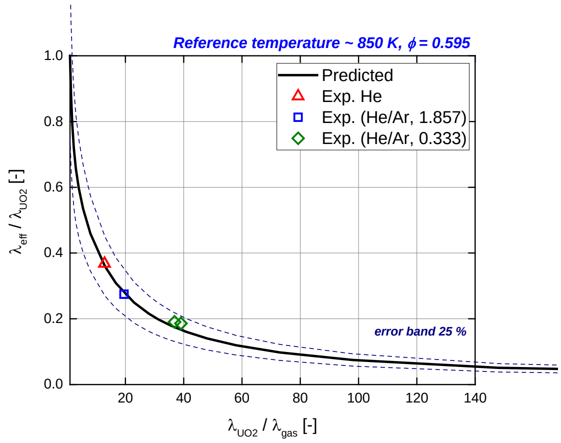

Fig. 1. Calculated effective thermal conductivity of UO2 powder in various gases, in comparison with experimental data.

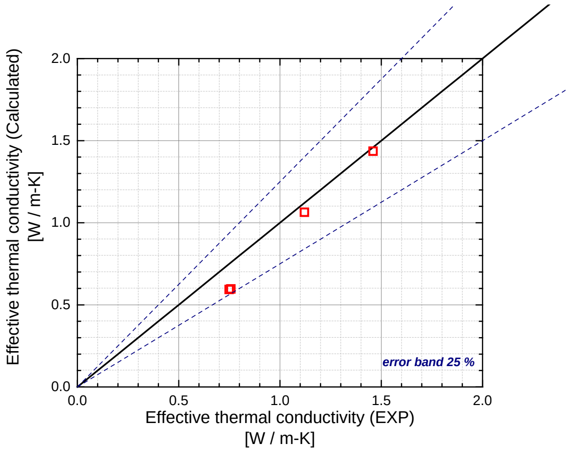

Fig. 2. Comparison of effective thermal conductivity of UO2 powder in various gases at a temperature of 850 K and packing fraction of 0.595.

3. Conclusions

During LOCAs, fuel pellet can be fragmented and relocated due to the ballooned clad, high burnup, and internal overpressure and so on. To simulate these phenomena, the models considering FFRD phenomena have recently implemented in the SPACE. As a part of these improvements, thermal calculation model was newly implemented in the SPACE and verified by comparing with analytic solutions in the previous study.

In this study, the implemented model for effective thermal conductivity was assessed by comparing with experimental data for measured effective thermal conductivity of uranium oxide powder in the various gases. The predicted values of effective thermal conductivity are well matched with measured data. From this, it is clear that the correlation by Chiew and Glandt reproduces the experimental data quite well within 25% of uncertainty. Based on these, we can conclude that this model for effective thermal conductivity is possible to predict the thermal conductivity of crumble fuel in the SPACE. As a further work, we will simulate an integral effect test to validate the newly implemented models for FFRD phenomena.

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