Prediction of peak cladding temperature of spent fuel assembly with porous model in dry storage

Doyun Kim[a]*, Seung-hwan Yu[a]
[a] *Radwaste Transportation and Storage Research Team, Korea Atomic Energy Research Institute, Daejeon 34057, Republic of Korea*
dykim0129@kaeri.re.kr

1. Introduction

Porous media assumption is effective method for modeling spent nuclear assembly in the view of computational cost. It assumes fuel rod and backfill gas as a homogeneous media that has equivalent thermal-hydraulic characteristics with real spent nuclear fuel assembly. Therefore, to define accurate effective thermal conductivity is important to represent the heat transfer and peak cladding temperature of actual spent nuclear fuel assembly. CFD code is widely used for a thermal analysis in a dry cask.

Herein, method to calculate effective thermal conductivity in a single assembly based on the Single Assembly Heat Transfer Test(SAHTT)[1] is introduced, and the predicted peak cladding temperatures with porous model is compared with the temperature results with detailed model.

2. Method and results

In this section, calculation method of effective thermal conductivity and the discussion of the temperature prediction results with porous media model based on ANSYS Fluent are described.

2.1 SAHTT description

SAHTT contains a WH type 15 x 15 PWR fuel assembly in a cask with unheated 15 rods. In this study, we consider backfill gas of air and vertical inclination test case.

2.2 Effective thermal conductivity calculation

Among several method for calculating effective thermal conductivity, we assessed analytically calculated conductivity assuming fuel assembly as a homogeneous porous media that generates volumetrically uniform heat. Then, analytical solution of temperature in the center of a square is as followed if the heat generation rate is constant. [2]

$$T(0,0) = \frac{q'''a^2}{2k} - \frac{16q'''a^2}{k\pi^3}\sum_{n=0}^{\infty}\frac{(-1)^n}{(2n+1)^3\cosh[(2n+1)\pi/2]} \tag{1}$$

If the outer surface temperature is fixed, the effective thermal conductivity is as follow.

$$k_e = \frac{Q}{4L_a(T_o - T_s)}(0.2947) \tag{2}$$

According to the equation, center temperature that equals to peak cladding temperature needs to obtain effective thermal conductivity as given heat generation rate and outer surface temperature. Thus, we modeled 2D fuel assembly in detail, and calculated peak cladding temperature and effective thermal conductivity as shown in Fig. 1.

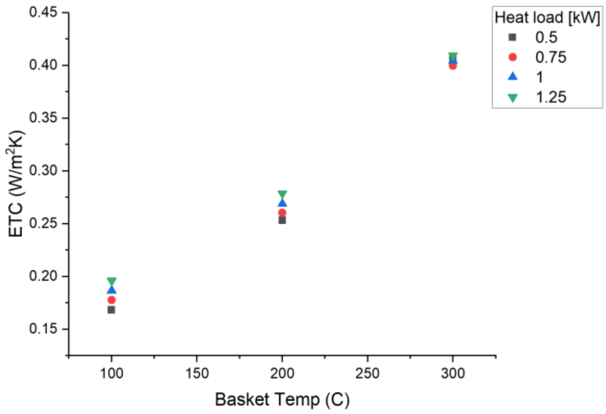

Fig. 1. Effective thermal conductivity as a function of heat load and basket temperature

Effective thermal conductivity is mainly dependent on the basket temperature, not on the heat load. The effect of heat load on effective thermal conductivity decreased as basket temperature increase.

2.3 Temperature prediction results with porous model

3D SAHTT modeling was performed for the thermal analysis with porous model applying effective thermal conductivity obtained above. As a flow resistance in the porous media, only viscous resistance according to Darcy-Weisbach equation[3] is considered while inertial resistance is neglected because of low natural convection velocity in the fuel assembly. Results of the peak cladding temperatures are shown in Table I. The results shows that porous model has more conservatism because it has higher peak cladding temperature when the heat load and the basket temperature is high, which represents an early phase after fuel assemblies are loaded in a dry cask with high cladding temperature. However, discrepancy between the peak cladding temperature with porous model and detailed model is small, lower than 1.5%.

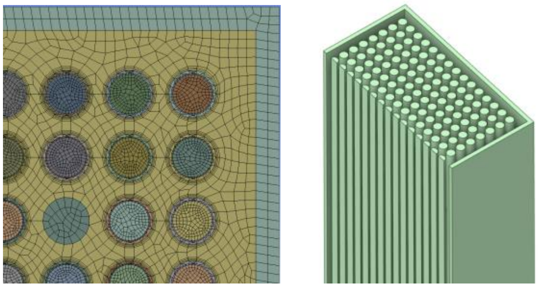

Fig. 2. 2D and 3D detailed model of SAHTT fuel assembly

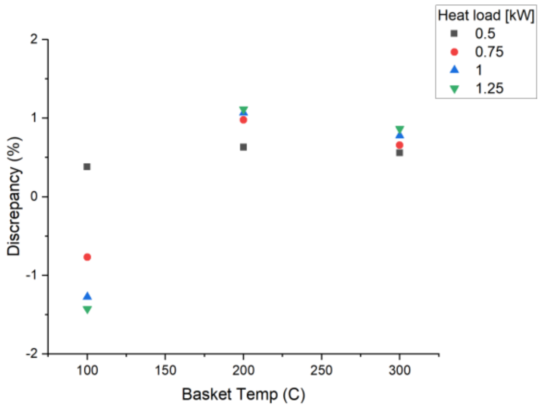

Fig. 3. Peak cladding temperature discrepancy of porous model compared to detailed model

Table I: Comparison of peak cladding temperature

Peak cladding temperature [°C]					
	Basket temp. [°C]	Heat load [kW]			
		0.5	0.75	1	1.25
Porous model	100	158.4	180.8	201.7	221.2
	200	239.8	258.2	274.9	290.6
	300	234.9	337.8	350.1	361.7
	Basket temp. [°C]	Heat load [kW]			
		0.5	0.75	1	1.25
Detailed model	100	157.8	182.2	204.3	224.4
	200	238.3	255.7	272.0	287.4
	300	323.1	335.6	347.4	358.6

In porous media, heat is transferred by conduction only, while the heat is transferred by both conduction and radiation in detailed model. Therefore, temperature profile with porous model seems to decrease linearly from its center to outside.

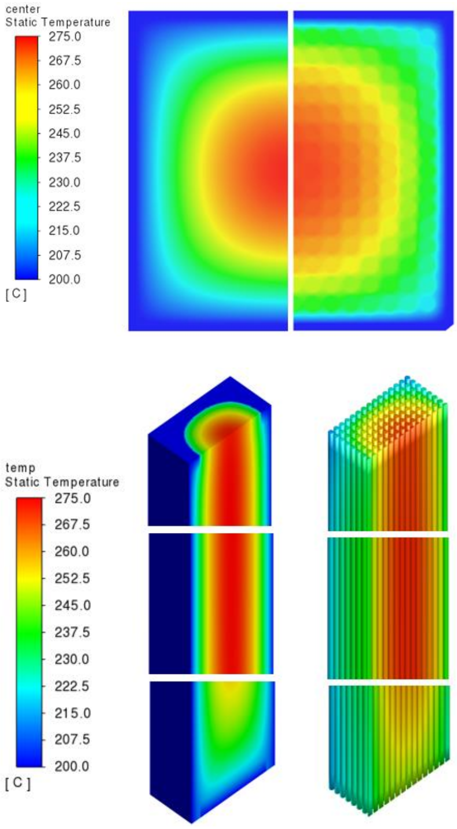

Fig. 4. Temperature distribution with porous and detailed model with 1kW of heat load and 300℃ of basket temperature

Axial temperature profiles are almost uniform except for the bottom region where relatively cold air flows into the fuel assembly. Thermal developing region is long in case of the porous model because its natural convection velocity is slower than that of the detailed model.

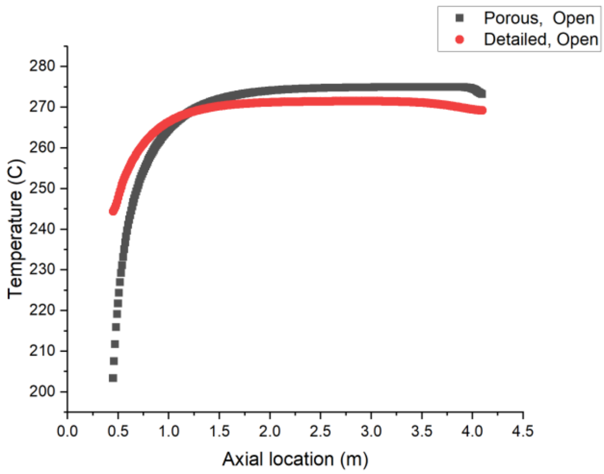

Fig. 5. Axial temperature profile

3. Summary and conclusions

Effective thermal conductivity correlation for porous model was analytically obtained, and the values in given heat load and basket temperature were calculated based on the peak cladding temperatures with detailed model by CFD code. With the Effective thermal conductivity, 3D SAHTT simulation with porous model was conducted. The peak cladding temperature with porous model was slightly higher compared to the results with detailed model, and it means porous model has more conservatism.

4. Acknowledgement

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