The Effective Thermal Conductivity of Spent Fuel Assemblies for Spent Fuel Storage

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1. Introduction

Spent fuel storage and transport packages store spent fuel assemblies after a certain period of time. The package must be evaluate if it removes decay heat which is continuously generated from spent fuel assembly. Fuel assemblies have a array consisting of a number of fuel rod which is composed of fuel pellets and claddings. It is very complicated to detail modeling individual structures of fuel assembly and takes a lot analysis time. It can be simplified by modeling uniform area that occupy volume of the aggregate. In order to accurate calculation for the homogenized region, thermal properties of the region for radial and axial directions need to be determined by utilizing the characteristics of components. The properties of axial direction can be obtained by the area-weighted method. And that of radial direction can be calculated by the finite volume method. Therefore, 2D thermal analysis by using ANSYS Fluent v16.2 for the fuel assemblies such as WH OFA 17X17, WH 16X16 and Plus 7 was performed. And the effective thermal conductivities of each assembly which varies depending on temperature are calculated and the design basis fuel was determined.

2. Effective thermal conductivity

According to reference[1], the method which can obtain the effective thermal conductivities utilizing explicit model are presented. Heat diffusion equation for the square region which have same direction can be simplified. And the equation of the effective thermal conductivity is shown as follows.

$$k_e = \frac{Q}{4L(T_{\max} - T_s)} * 0.2947 \tag{1}$$

k_e : $the\ effective\ thermal\ conductivity\ (W/m \cdot K)$
Q: $assembly\ heat\ load\ (W)$
$T_{\max}$: $the\ \mathrm{max}imum\ temperature\ (K)$
T_b : $the\ basket\ temperature\ (K)$
L : $assembly\ active\ length\ (m)$

And the values of each assembly which obtained through 2D thermal analysis were used as temperature drops for the equation and the effective thermal conductivities were calculated.

2.1 Modeling of fuel assemblies

Spent nuclear fuel assemblies were modeled quadrantly for WH 16X16, WH OFA 17X17, PLUS7. The models is the cross-section of mid-section of the assemblies. The geometry contains nuclear fuel pellets and claddings. The gaps between pellets and claddings were taken into account. Guide tubes and Instrumentation tubes were also modeled. And helium and water were considered for the backfilled fluid.

2.2 boundary condition

The fixed wall temperatures for the case that it was backfilled with helium are 300K, 400K, 500K and 600K. And for the case which contains water, the wall temperatures which does not cause boiling of water were applied. Heat loads which were applied to the assembly were used for the same to compare conductivities. DO radiation model was applied for radiation calculation

3. Results and Conclusion

The effective thermal conductivities for three assemblies with helium were calculated first. these can be confirmed in Table 1. According to Table 1, There are little differences between the effective thermal conductivities. However, WH 16X16 assembly has overall lower trend. And it was determined for a design basis fuel to perform future analysis of the spent fuel waste package because it has conservative values. And 2D CFD analysis was additionally performed for the case that WH16X16 backfilled with water to analysis spent fuel pool. Temperature distributions of WH 16X16 backfilled with helium and water is shown in figure 2 & 3. Temperature drop of the case with water is much less than the other case with helium. And the effective thermal conductivity for the case with water has a higher value.

In this study, the effective thermal conductivities are obtained by 2D CFD analysis and these could be applied to the further thermal analysis of spent fuel storage and transport packages.

Table 1. Results of the calculated effective thermal conductivities

		Boundary condition			
		300K	400K	500K	600K
Effective Thermal Conductivity	WH 17X17	0.4586	0.5635	0.7329	0.7431
	WH 16X16	0.3665	0.5051	0.6026	0.9123
	PLUS 7	0.3967	0.4925	0.6555	0.9094

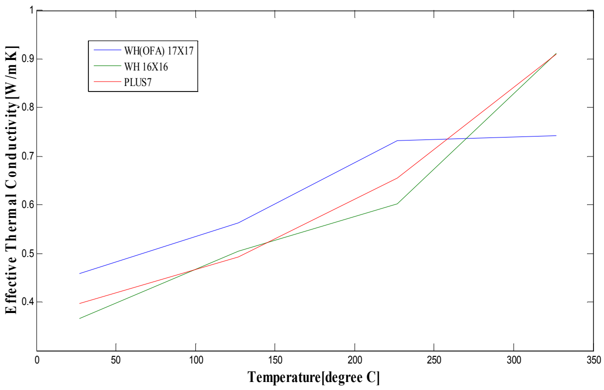

Fig. 1. the calculated effective thermal conductivities of each fuel assembly.

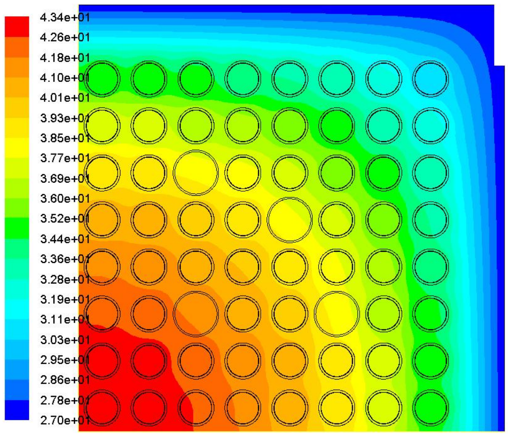

Fig. 2. Temperature distribution of WH 16X16 assembly backfilled with water.

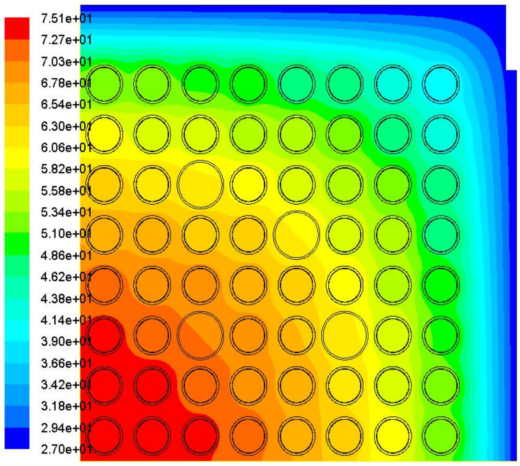

Fig. 3. Temperature distribution of WH 16X16 assembly backfilled with helium.

4. Acknowledgements

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5. References

[1] U.S. Department of Energy, "Spent Nuclear Fuel Effective Thermal Conductivity Report", 1996.

[2] U.S.NRC, "Computational Fluid Dynamics Best Practice Guidelines for Dry Cask Applications", NUREG-2152 (2013).