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Thermal Evaluation of Storage Rack with an Advanced Neutron Absorber during Normal Operation

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1. Introduction

Spent nuclear fuel that has been withdrawn from reactor is safely stored and managed in the storage rack of spent fuel pool for a period of time due to its high radioactivity and decay heat. The rack structure is consisted of square boxes to store fuel assemblies at regular intervals. The storage capacity of the domestic wet storage site is expected to reach saturation from Hanbit in 2024 to Sin-wolseong in 2038 and accordingly management alternatives are urgently taken[1]. Since installation of the dense rack is considered in the short term, it is necessary to urgently develop an advanced neutron absorber which can be applied to a spent nuclear fuel storage facility. Neutron absorber is the material for controlling the reactivity. A material which has excellent thermal neutron absorption ability, high strength and corrosion resistance must be selected as the neutron absorber. Existing neutron absorbers are made of boron which has a good thermal absorption ability such as BORAL and METAMIC[2]. However, possible problems have been reported in using the boron-based neutron absorber for wet storage facility. Gadolinium is known to have higher neutron absorption cross-section than that of boron. And the strength of duplex stainless steel is about 1.5 times higher than stainless steel 304 which has been frequently used as a structural material. Therefore, duplex stainless steel which contains gadolinium is in consideration as an advanced neutron absorber.

In this study, Thermal analysis was conducted to evaluate the impact of the advanced neutron absorber by using ANSYS FLUENT v16.2. The main purpose of this study to confirm the thermal integrity when the advanced neutron absorber is applied as neutron absorber. According to reference[3,4], the maximum normal heat load with normal cooling systems in operation and assuming a single active failure with a loss of all offsite power, the bulk temperature of the pool will be kept at or below 60℃(140˚F) with maximum heat generation. Further, coolant must always be able to maintain a minimum water level which is necessary for decay heat removal and radiation shielding.

2. Modeling

The Kori unit 1 was set to a reference model in order to evaluate the cooling capacity of SFP(Spent Fuel Pool). The specification of the model is 10.439m (W)X 8.636m (L) X 12.04m (H) and is shown in figure 1. It has been operated by the forced convection with pump(3000 gpm). And it is divided into Region I that the fresh fuel is stored and Region II that the fuel which is combusted and came from reactor can be stored. Therefore, decay heat occur only in Region II not Region I. To carry out thermal analysis conservatively, the CFD model was considered for a part of the Region II. The model is consisted of 9X11 rack structures and shown in figure 2. And the arrangement of rack structures is shown in figure 3[5]. The common neutron absorber is a type of composite walls such as BORAL and stainless steel. In this evaluation, the integral structure which contains 1 wt.% Gd + 1.2wt.% B was modeled. The rack structure is above the pool bottom and its length is 4.6799m. And the height of the CFD model is 12.04m.

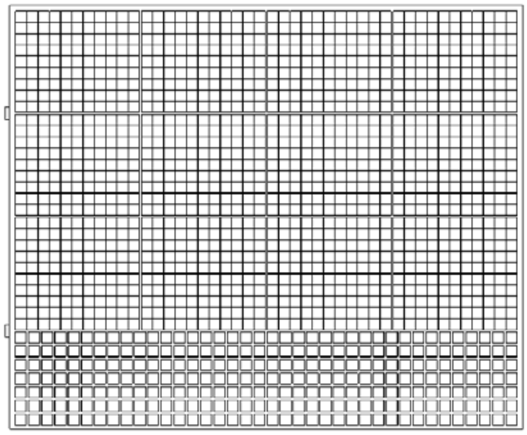

Figure 1. The reference model

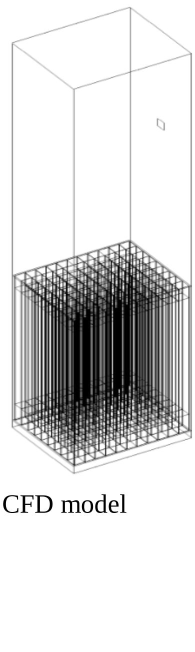

Figure 2. 3D CFD model

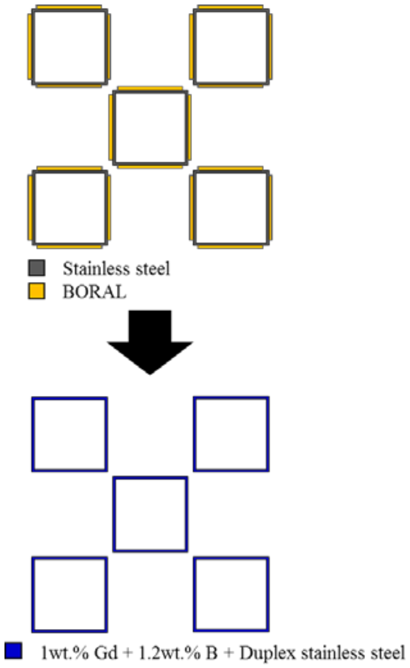

Figure 3. Design concept of rack structures.

2.1. Numerical modeling

Initial pool temperature and inlet temperature are 303.2K and 298.2K. The inlet is the bottom surface of the CFD model. And the outlet position was assumed to be the same as the position of the reference model. The mass flow rate of the reference model is 3000gpm and that of the CFD model is 185.8gpm when it applied equivalently. In order to calculate conservatively, the flow rate was applied as half, 92.9 gpm.

For boundary conditions, no-slip condition and adiabatic condition were used for the outer wall. The wall which release heat to the air was applied in consideration of its correlation with convective heat transfer. The decay heat is refered in reference[6,7]. The calculated decay heat for a fuel assembly was 1738W and this value was applied in each fuel cell.

2.1.1. Porous media model

The rack structures in Region II are arranged as figure 3, spent fuel assemblies are stored between the internal and external of the structures. Since the assembly structure is very complex, it takes a long time to analyze the shape. Therefore, the fuel region was modeled as porous media with flow resistances. Equation (1) gives the FLUETN source term in one dimension. The viscous term is first, followed by the inertial loss term[8].

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$$-\frac{\mathrm{dP}}{\mathrm{dz}} = D \cdot \mu V + C \cdot \frac{1}{2}\rho V \cdot |V| \qquad (1)$$

P: pressure
D: the viscos coefficient
C: the inertial coefficient
ρ: density
V: velocity

In three dimensions, the coefficients D and C represent matrices. These values are input parameters for the FLUENT porous media model.

The viscous resistance was calculated by using method of friction coefficient as follows. It is assumed that viscous losses are uniform along the length. Equation (2) represents the pressure loss over a distance L with hydraulic diameter, D_H.

$$-\frac{\mathrm{dP}}{\mathrm{dz}} = f \cdot \frac{L}{D_H} \cdot \frac{1}{2}\rho V^2 \qquad (2)$$

f: friction factor
L: length
$\mathrm{D_H}$: *hydraulic diameter*

2.1.2. Effective thermal conductivity for porous region

Fuel region was simplified by modeling a uniform area that occupies a volume of the aggregate. In order to accurate calculation for the homogenized region, thermal properties of the region is needed to be determined.

According to reference [9], the ETC(Effective Thermal Conductivity) can be obtained by using heat diffusion equation and temperature drops which are calculated by explicit model.

$$\mathrm{k_e} = \frac{Q}{4L(T_{max} - T_S)} \cdot 0.2947 \qquad (3)$$

$\mathrm{k_e}$: *the effecitve thermal conductivity of fuel region*
$\mathrm{L_a}$: the active length of fuel assembly
$\mathrm{T_{max}}$: *the maximum temperature of fuel region*
$\mathrm{T_s}$: *surface temperature*

In Porous model in FLUENT, the ETC is used in equation (4)

$$\mathrm{k} = \phi \mathrm{k_f} + (1 - \phi) k_e \qquad (4)$$

k: the effectieve conductivity in FLUNET's porous model
$\mathrm{k_f}$: *the fluid conductivity*
ϕ: *the porosity in porous region*

3. Results and Discussion

Temperature distribution is shown in figure 4. In pool bottom region near the inlet shows a relatively low tendency and heat generated from the fuel assemblies is transmitted to the pool upper region by the vertical flow. Also, temperature gradient appear in rack structures for the axial direction and temperature is uniformly distributed in the pool upper region. Table 1 presents the calculated results. The maximum temperature is 306.63K and does not exceed the 333.15K (60℃). The maximum temperature of the neutron absorber is 306.48K.

In this study, the partial SFP with the neutron absorber was modeled and thermal analysis of the model was conducted to assess cooling capacity. Although it was in the conservative condition that the pump capacity is half, it did not exceed the maximum operating temperature. As results, it is sufficiently accommodate to apply the advanced neutron absorber to the storage rack.

Table 2. Temperature results

Temperatures	Values
Max. partial SFP temperature	306.63K
Min. partial SFP temperature	298.20K
Temperature gradient	8.43K
Max. absorber temperature	306.48K

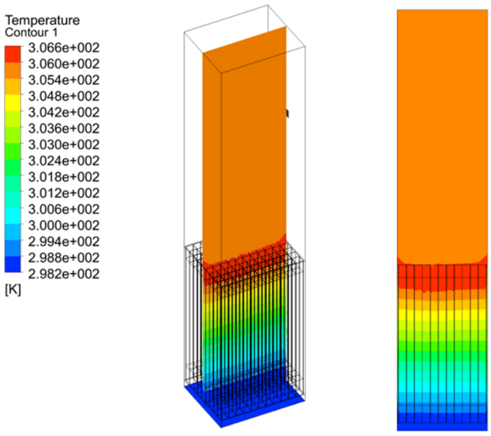

Figure 4. Temperature distribution of the CFD model

ACKNOWLEDGEMENTS

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REFERENCES

[1] 사용후핵연료 공론위원회, "사용후핵연료관리방안에 대한 잠재 시나리오 및 공론화프로그램 논의 주요내용", 2014.
[2] EPRI, "Handbook on Neutron Absorber Materials for Spent Nuclear Fuel Applications", 2005
[3]US.NRC, "Standard Review Plan for Spent Fuel Dry Storage Facilities", NUREG-1567, 2000
[4] 원자력안전위원회 고시 제 2015-019 호, "사용후핵연료 중간저장시설의 구조 및 설비에 관한 세부기술기준".
[5] Holtec, "Spent Fuel Pool Racks Modifications with Poison Material Inserts in ANO Unit 1", Holtec Report HI-2022867.
[6]Dong-Hyeong Yoon, Jin-Hyuck Kim, Kwang-Won Seul, "CFD Evaluation of SFP Cooling Capacity during Normal Operating Conditions", KNS, Oct 25-26, 2012.
[7]Jin-Hyuck Kim, Dong-Hyeong Yoon, Kwang-Won Seul, "MARS-KS simulation for calculating the cooling capacity of spent fuel pool", KNS, Oct 25-26, 2012
[8] US.NRC, "Predictions of Spent Fuel Heatup After a Complete Loss of Spent Fuel Pool Coolant", NUREG-1726, 2000
[9] U.S Department of Energy, "Spent Nuclear Fuel Effective Thermal Conductivity Report", 1996