Estimation for Storage Capacity in the Spent Fuel Pool Using CFD Analysis

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1. Introduction

The spent fuel assemblies are stored in the tray bundles in a spent fuel pool (SFP). Increasing the quantity of the discharged fuel assemblies will result in higher SFP decay heat loads. Therefore, the thermal hydraulic investigation for storage capacity in the pool is demanded in the condition of higher SFP decay heat loads according to addition of tray bundles. This study is performed to estimate the storage capacity in the SFP according to the decay heat expansion using CFD analysis.

2. Numerical Analysis

2.1 Analysis Scope

Fig. 1 is the schematic of a SFP used in this analysis. Fuel assemblies are loaded in each tray and trays are stacked in the water pool enclosed by concrete wall. Dimension of a tray is 60"(w)×42.5"(b)×5.5"(h) and there are 1,764(14 ea×7 ea×18 layer) or 1862(19 layer) trays in pool. Cooling water that passes through heat exchanger is supplied in the SFP through 4 inlet nozzles. There are 4" gaps between trays and these gaps allow water flow.

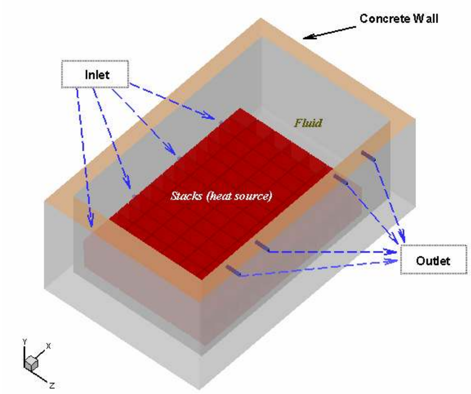


Fig. 1. Schematic of a SFP model for numerical analysis.

2.2 Numerical Schemes

The FLUENT code based on the finite volume method was used for the thermal flow analysis. Mass, momentum, turbulence and energy conservation equations were used as governing equations. Adopted turbulent model is the RNG k-ε model that can derive the local effective viscosity using differential formula. This turbulent model is suitable in this flow field that the low Reynolds flow effect is expected in the gap between trays. Fig. 2 shows the grid system used in the CFD analysis and the number of grid is 2,143,680. Sensitivity on other turbulence models and grid systems was investigated and all results were similar with the result of standard model.

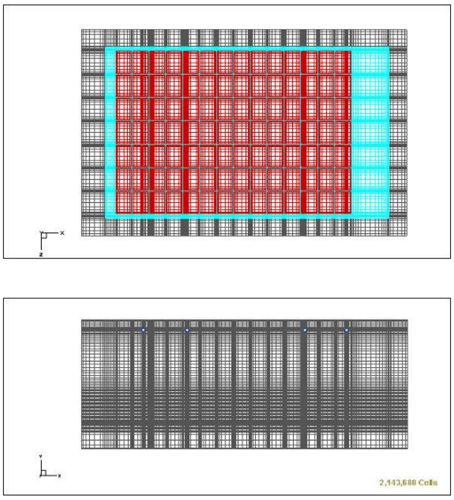


Fig. 2. Grid system used in the CFD analysis.

2.3 Boundary Conditions

Gaps between adjacent trays are incorporated in the model. Decay heat is defined as the function of height depicted in Fig. 3. This analysis method is different with previous analysis method [1]. The properties of water are defined as the function of temperature. Computation conditions are divided into 3 parts (normal, abnormal and emergency) [2]. Boundary conditions in each part are shown in Table I ~ III.

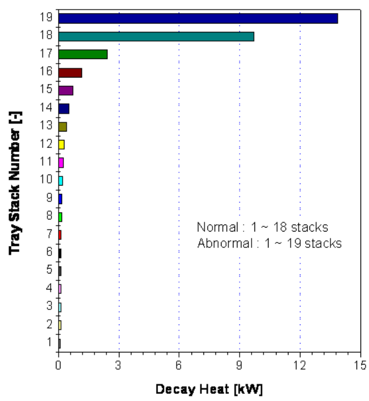


Fig. 3. Decay heat condition according to the height of tray.

Table I: Boundary conditions in normal condition

Description	Case	Boundary Conditions
Normal Condition	Case 1	- Heat source : 18 Stacks (1.643 MW) - T_{in} = 28.73 °C , Q_{in} = 146 L/s (HX 2ea) - Steady, Mixed Convection - $\partial T / \partial x_i = 0$ (at free surface, outer wall)
	Case 2	- Heat source : 18 Stacks (1.643 MW) - T_{in} = 34.85°C , Q_{in} = 146 L/s (HX 2ea) - Steady, Mixed Convection - $\partial T / \partial x_i = 0$ (at free surface, outer wall)
	Case 3	- Heat source : 18 Stacks (1.643 MW) - T_{in} = 28.73 °C , Q_{in} = 73 L/s (HX 2ea) - Steady, Mixed Convection - $\partial T / \partial x_i = 0$ (at free surface, outer wall)

Table II: Boundary conditions in abnormal condition

Description	Case	Boundary Conditions
Abnormal Condition	Case 4	- Heat source : 19 Stacks (3.0 MW) - T_{in} = 28.73 °C , Q_{in} = 146 L/s (HX 2ea) - Steady, Mixed Convection - $\partial T / \partial x_i = 0$ (at free surface, outer wall)
	Case 5	- Heat source : 19 Stacks (3.0 MW) - T_{in} = 38.85 °C , Q_{in} = 146 L/s (HX 2ea) - Steady, Mixed Convection - $\partial T / \partial x_i = 0$ (at free surface, outer wall)
	Case 6	- Heat source : 19 Stacks (3.0 MW) - T_{in} = 42.85 °C , Q_{in} = 146 L/s (HX 2ea) - Steady, Mixed Convection - $\partial T / \partial x_i = 0$ (at free surface, outer wall)

Table III: Boundary conditions in emergency condition

Description	Case	Boundary Conditions
Emergency Condition	Case 7	- Heat source : 18 Stacks (1.643 MW) - T_{in} = 31.16 °C , Q_{in} = 146 L/s → 0 L/s - Natural Convection - Unsteady (0 sec → 43,200 sec (12hours)) - $\partial T / \partial x_i = 0$ (at free surface, outer wall)

3. Results and Discussion

Fig. 4 shows the path-line distribution of cooling water flowing into inlet nozzle of the SFP. Cooling water flowing into the SFP goes to outlet as showing the complicated flow shape. Fig. 5 shows temperature distributions in vertical section in the SFP. Water temperature in upper part of the SFP doesn't rise rapidly in spite of higher decay heat in upper trays. Table IV is the temperature results in analysis conditions delineated in Table I ~ III. Entire temperature results illustrate that the higher inlet temperature, the less temperature rising in the SFP. This is due to the water property change according to the inlet temperature change.

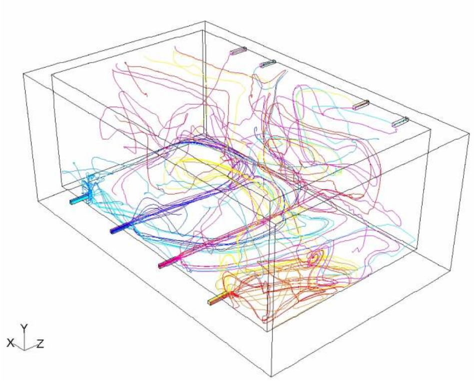
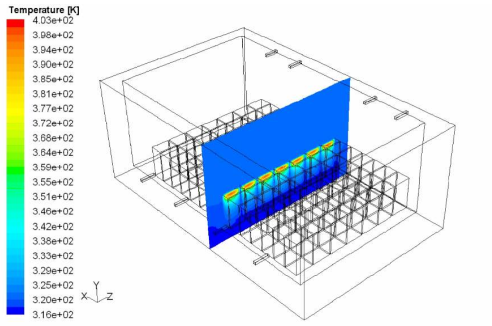
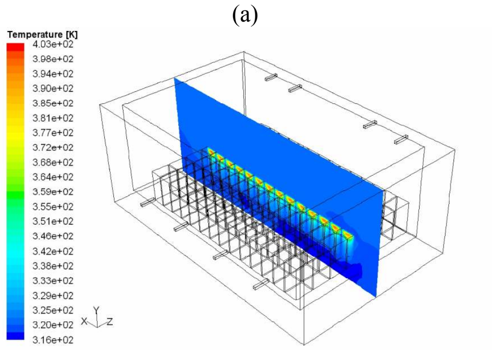


Fig. 4. Path-line distribution of cooling water flowing into inlet nozzle of the SFP.



(a)



(b)

Fig. 5. Temperature distributions in vertical sections in the SFP.

Table IV: Temperature results in each analysis conditions

Case	Condition	Inlet Temp. (T_{in})	Outlet Temp. (T_{out})	Avg. Temp. (T_{avg})	Max. Temp. (T_{max})	Temperature Rising	
						$\Delta T_1 = T_{out} - T_{in}$	$\Delta T_2 = T_{avg} - T_{in}$
1	Normal	28.73 °C	31.37 °C	31.16 °C	33 °C	2.64 °C	2.43 °C
2	Normal	34.85 °C	37.47 °C	37.25 °C	38.5 °C	2.62 °C	2.4 °C
3	Normal	28.73 °C	34.08 °C	33.89 °C	35.39 °C	5.35 °C	5.16 °C
4	Abnormal	28.73 °C	34.05 °C	33.72 °C	36.52 °C	5.32 °C	4.99 °C
5	Abnormal	38.85 °C	43.82 °C	43.58 °C	46.2 °C	4.97 °C	4.73 °C
6	Abnormal	42.85 °C	47.75 °C	47.53 °C	49.33 °C	4.9 °C	4.68 °C
7	Emergency	31.16 °C	-	40.27 °C	41.38 °C	-	9.11 °C

4. Conclusions

In this study, estimation for the storage capacity in a SFP is carried out using CFD analysis. Numerical computation was performed in normal, abnormal and emergency condition and temperature change in the SFP was investigated. Water temperature in upper part of the SFP doesn't rise rapidly in spite of higher decay heat in upper trays. Entire temperature results show that the higher inlet temperature, the less temperature rising in the SFP.

REFERENCES

[1] Hotec International, Ulchin Unit 3&4 Local Temperature Analysis, HI-2073666, 2007.
[2] KHNP, KOPEC & Jace Korea, Inc., The Safety Analysis Report for Spent Fuel Storage Tray, W-340-C416-001, 2006.