Sensitivity Analysis of COBRA-SFS for Sub-Channel Analysis of PWR Fuel Assembly

Ju-Chan Lee*, Doyun Kim, Kyung-Sik Bang, and Seunghwan Yu

KAERI, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Republic of Korea
* *Corresponding author: sjclee@kaeri.re.kr*

1. Introduction

Spent nuclear fuel should be maintained its integrity during the long-term dry storage. Detailed temperature distributions of the spent fuel assembly are required to evaluate the integrity of the dry storage system. COBRA-SFS code [1] was developed to predict the flow and temperature distributions in spent fuel storage system and fuel assemblies. In this study, sub-channel analyses of PWR single fuel assembly were performed according to the thermal parameters to evaluate the sensitivity of the COBRA-SFS.

2. Methods and Results

2.1 Analysis model

In this study, Single Assembly Heat Transfer Test (SAHTT) model [2] was selected as the sub-channel analysis using the COBRA-SFS. It was developed at the PNL to investigate heat transfer characteristics of spent PWR fuel under dry storage conditions.

Fig. 1 show a sub-channel analysis model. Fuel assembly has a 15 x 15 array of fuel rods with a diameter of 10.7 mm (0.42 in.) and a nominal pitch of 14.3 mm (0.563 in.). Control rod thimbles were modeled with unheated rods. The analysis model consists of 256 sub-channels, 225 rods, and 8 slab nodes modeling the canister wall. The heat generation rate was axially uniform with total power of 1.0 kW. Analysis condition was considered for the vertical orientation with the air backfill inside the canister.

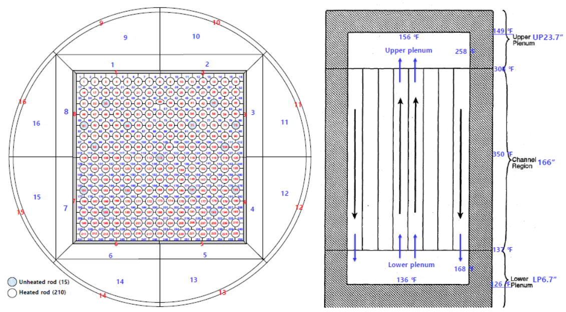

Fig. 1. Sub-channel analysis model for SAHTT.

Sub-channel analyses of PWR single assembly were performed to predict the effect of thermal parameters such as surface emissivity, convective heat transfer, and flow resistance on the PCT (Peak Cladding Temperature).

2.2 *Results and discussion*

Table 1 to 5 summarize the sub-channel analysis results according the thermal parameters. Radiation heat transfer is mainly generated between the fuel rod and the basket walls. Sub-channel analysis was performed according to the emissivity of the fuel rods and the basket wall. The PCT was affected by the emissivity of the fuel rod and the basket. In particular, the basket emissivity had a significant effect on the PCT.

Convective heat transfer coefficient is defined in terms of the Nusselt number. The Nusselt number is the ratio of convection to conduction with a fluid. The Nusselt number is defined as a function of Raynolds number and Prandtl number.

$$H = Nu\frac{k}{D_c} = (a_1 Re^{a_2}\,Pr^{a_3} + a_4)\frac{k}{D_c} \quad (1)$$

Heat transfer from the rods and walls to the coolant was prescribed using the film coefficient Nu = 3.66 [3]. Nusselt numbers were considered as Nu = 1.0, 3.66, and 5.0. As a result of analysis, the PCT decreased as the Nusselt number increased. The range of the Nusselt number is around 3.66. Therefore, the effect of the Nusselt number will not be significant on the PCT.

The flow resistance is important convection parameter. Main flow resistance of the cask is rod and wall surface drag, and spacer grid losses. Wall friction factor is determined from the Blasius relation.

$$f = aRe^{b\ a_3} + c \quad (2)$$

The friction factor is considered as f = 100/Re [4] for laminar flow along cylinders arranged in a square array such as PWR fuels. The friction factor is considered as f = 64/Re [3] for fully developed laminar pipe flow. In this study, the friction factors were considered as f = 64/Re, 100/Re and 150/Re.

The pressure loss due to form drag on local obstructions in the flow field such as spacer grids is given by

$$\triangle P = \frac{K|\dot{m}|\,|\dot{m}|}{2g_c\,\rho\,A^2}\ \left(K = \frac{\triangle P}{\rho v^2/2}\right) \quad (3)$$

In this study, pressure loss coefficients from the spacer grids were considered as K=1 to K=16.

As a result of the analysis according to the flow resistance coefficients, the PCT was affected by the wall friction factor. But the loss coefficients from the spacer grid had no effect on the PCT. Therefore, pressure loss from the spacer grids can be neglected in the sub-channel analysis.

Table 1. Calculated temperatures according to the surface emissivity of fuel cladding

Emissivity of cladding	Cladding temp. (°C)		Basket temperature (°C)
	Max. (Rod-128)	Min. (Rod-1)	
0.4	297.4	240.1	224.0
0.6	289.2	240.8	224.5
0.8	282.8	241.5	224.8

Table 2. Calculated temperatures according to the surface emissivity of fuel basket

Emissivity of basket	Cladding temp. (°C)		Basket temperature (°C)
	Max. (Rod-128)	Min. (Rod-1)	
0.25	289.2	240.8	224.5
0.4	273.5	223.1	210.9
0.6	262.9	211.8	202.5

Table 3. Calculated temperatures according to the Nusselt number

Nusselt number (Nu)	Cladding temp. (°C)		Basket temperature (°C)
	Max. (Rod-128)	Min. (Rod-1)	
1.00	298.3	245.9	222.8
3.66	289.2	240.8	224.5
5.00	284.8	238.5	224.3

Table 4. Calculated temperatures according to the wall friction factor

Friction factor (f)	Cladding temp. (°C)		Basket temperature (°C)
	Max. (Rod-128)	Min. (Rod-1)	
64/Re	286.9	238.6	224.4
100/Re	289.2	240.8	224.5
150/Re	290.7	242.2	225.8

Table 5. Calculated temperatures according to the loss coefficient of spacer grid

Loss coefficient (K)	Cladding temp. (°C)		Basket temperature (°C)
	Max. (Rod-128)	Min. (Rod-1)	
1,4	289.4	241.0	224.6
2,8	289.2	240.8	224.5
4,16	289.1	240.7	224.4

3. Conclusions

In this study, sensitivity analyzes were performed to evaluate the effect of thermal parameters on PCT in the COBRA-SFS. The main results are as follows:

(i) The PCT was affected by the emissivity of fuel rod and basket wall. In particular, the basket emissivity had a significant effect on the PCT.

(ii) The PCT was affected by the Nu (Nusselt number), but the range of the Nu is around 3.66. So, the effect of the Nu will not be significant on the PCT.

(iii) The PCT was affected by the wall friction factor, but the effect of the form loss coefficients from the spacer grid was negligible.

The results obtained from this work can be used to predict the detailed temperature distributions of spent fuel assembly.

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