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Thermal Analysis of Simulated Fuel Assembly for the Design of Drying Test Equipment

Ju-Chan Lee*, K.S. Bang, S.H. Yu, K.S. Seo, S.S. Cho, W.S. Choi
KAERI, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Korea
**Corresponding author: sjclee@kaeri.re.kr*

1. Introduction

KAERI has been developing the drying equipment for the dry transport and storage of spent nuclear fuel [1]. There are two types of drying system, vacuum and forced helium drying [2]. The vacuum drying process depends on the reduced pressure to evaporate moisture from the canister. In the forced helium drying process, moisture is removed by blowing down the canister by helium gas.

Drying test equipment is being designed to simulate the drying process for one spent fuel assembly canister. In order to obtain the design data for the test equipment, thermal analyses have been performed for one assembly fuel basket as variations of decay heat load, basket wall temperatures and gas coolant conditions.

The 17ACE7 PWR assembly for the Westing house type reactor was selected as a design basis fuel for the drying test equipment. Simulated fuel assembly will be used to simulate the PWR spent fuel assembly in the test equipment. The dimensions and shape of the simulated fuel are same as the real fuel assembly. The 17ACE7 assembly has 17x17 rod array with 264 rods, 24 control rod's guide tubes and one instrumentation tube. All 264 rods are heated rods for the real spent fuel assembly. If all the rods are heated rods in the simulated fuel assembly, the heater power cable may interfere with the gas flow in the basket. Therefore, partial heating conditions with some heated rods or guide tubes are considered in the design of simulated fuel assembly.

Thermal analyses were performed for the real assembly and simulated fuel with partial heating conditions to obtain the design data for the simulated fuel assembly.

2. Thermal Analysis Model

The 17ACE7 fuel assembly has 17x17 rod array with 264 rods, 24 control rod guide tubes and 1 instrumentation tube as shown in Fig. 1(a). Outer diameter of fuel rod is 9.5 mm and fuel rod pitch is 12.7 mm. Two-dimensional CFD model was constructed for a single assembly basket as shown in. Fig. 1(b). Two-dimensional model can be used to approximate the three-dimensional design because of the similar temperature distributions along the longitudinal direction.

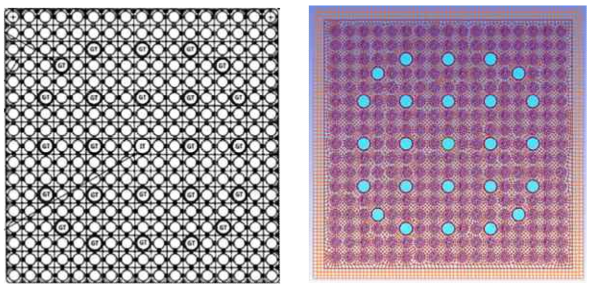
The FLUENT [3] was used to calculate the temperature distributions of fuel basket. For conduction and radiation heat transfer analyses, the steady-state energy equation was solved with a second-order discretization.

Thermal analyses were performed for a single fuel basket as variations of the decay heat load, the basket wall temperature and the environment inside the basket. The basic analysis conditions are the decay heat of 800 W from the single assembly, the basket wall temperature of 240 ℃, and the interior environment of helium gas. The ranges of the analysis condition are as follows.

- Decay heat load : 600 W, 800 W, 1000 W, 1200 W
- Basket wall temp. : 120 ℃, 180 ℃, 240 ℃, 300 ℃
- Interior environment of basket : helium, air, vacuum

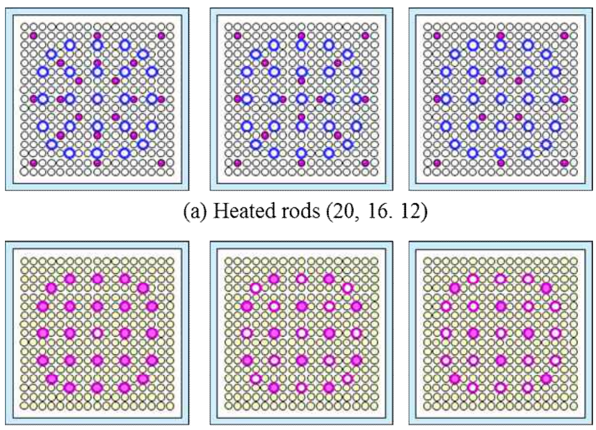
In addition, thermal analyses were performed for the real spent fuel assembly and simulated fuel assembly with partial heating condition of some rods or guide tubes. Fig. 2 shows the partial heating conditions of some rods or guide tubes.

- 264 heated rod (real fuel assembly)
- Heated rods : 20 rods, 16 rods, 12 rods
- Heated guide tubes : 24 tubes, 12 tubes, 8 tubes



(a) Cross section of 17ACE7 (b) Thermal analysis model

Fig. 1. 17ACE7 assembly and thermal analysis model



(a) Heated rods (20, 16. 12)

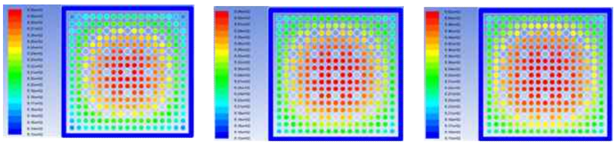
(b) Heated guide tubes (24, 12, 8)

Fig. 2. Heating condition for simulated fuel assembly

3. Results and Discussions

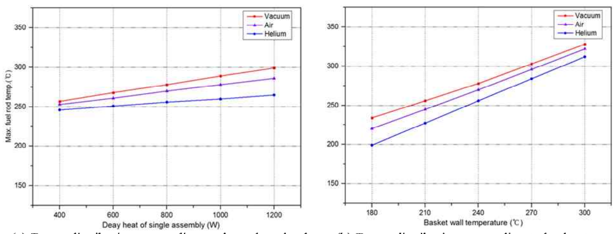
Thermal analyses were carried out for a single fuel basket. Fig. 3 shows the temperature contours for helium, air and vacuum environment condition. Thermal conductivity of helium is about 5 times higher than that of air. High thermal conduction reduces the temperature gradient across the entire fuel assembly in the helium environment. Heat is transferred only by the radiation under vacuum environment. The fuel rod temperatures in the vacuum environment are slightly higher than the temperatures calculated in the air or helium environment.

Fig. 4 shows the temperature distributions of fuel rod for range of decay heat loads (Q = 400 ~ 1200 W) and basket wall temperatures (T = 180 ~ 300 ℃) in various gaseous environments. The fuel rod temperatures increased in proportion to the decay heat load and the basket wall temperature.



(a) Helium (b) Air (c) Vacuum

Fig. 3. Temperature contours for fuel basket



(a) Temp. distributions according to decay heat load (b) Temp. distributions according to basket temp.

Fig. 4. Temperature distribution of fuel rod

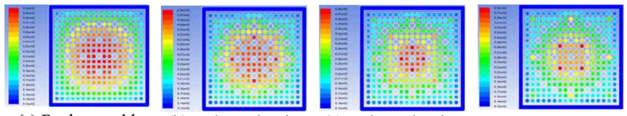
Table 1 shows the calculated temperatures for partial heating condition with some heated rods and guide tubes. Minimum and average temperatures were similar between the real fuel and simulated fuel assembly with partial heating conditions, but the maximum temperatures were higher in the simulated fuel than the real fuel assembly.

Fig. 5 and Fig. 6 show the temperature contours of fuel basket according to the heated rods and heated guide tubes. The temperature contours at heated guide tube conditions are similar to those of a real assembly compared to the heated rod conditions.

Temperature profiles of simulated fuel assembly deviate from the real fuel assembly as the number of heated guide tubes decreases. Therefore, heating condition with 24 heated guide tubes was selected as an optimum condition for the design of simulated fuel assembly. Flow resistance will be reduced by inserting the heater cable inside the guide tubes.

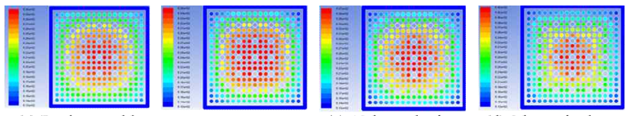
Table 1. Thermal analysis results for partial heating conditions

Heating condition	Tube's temp.(℃)		Rod's temp.(℃)		
	Min.	Max.	Min.	Aver.	Max.
Real assembly	249	256	242	249	256
20 heated rods	250	262	242	252	265
16 heated rods	250	262	242	251	265
12 heated rods	248	259	243	250	263
24 heated tubes	255	263	241	252	261
12 heated tubes	252	262	241	252	263
8 heated tubes	263	267	242	253	262



(a) Real assembly (b) 20 heated rods (c) 16 heated rods (d) 12 heated rods

Fig. 5. Temperature contours according to heated rods



(a) Real assembly (b) 24 heated tubes (c) 12 heated tubes (d) 8 heated tubes

Fig. 6. Temperature contours according to heated tubes

4. Conclusions

In this study, thermal analyses were performed for a single fuel basket to obtain the design data for simulated fuel assembly. Heating condition with 24 heated guide tubes was selected as an optimum condition for the design of simulated fuel assembly. Flow resistance will be reduced for the simulated fuel assembly by inserting the heater cable inside the guide tubes. The results of this study will be used as the basic data for the design and fabrication of drying test equipment.

REFERENCES

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