Heat Transfer Test by using a 1/2 Scale Horizontal Storage Module

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1. Introduction

Most nuclear power plants maintain their spent fuel discharged at a reactor in wet storage pools. However, after several years of use, many pools are filled to capacity. Therefore, finding a sufficient capacity for a storage is essential because of the continued delays in obtaining a safe, interim storage facility if nuclear power plants are to be allowed to continue to operate.

Horizontal storage module will be one solution for solving an interim storage problem. The horizontal storage module consists of two separate components: a horizontal module, and a canister. The horizontal module is made of concrete, which accomplishes the role of a radiation shield. The outer length of the horizontal storage module is 6,545 ㎜, its width is 4,215 ㎜ and the its height is 4,810 ㎜. It weighs approximately 257 tons. The horizontal storage module accommodates 24 PWR spent fuel assemblies with a burn-up of 50,000 MWD/MTU and a cooling time of 7 years. The decay heat from the 24 PWR spent fuel assemblies is 27.1 ㎾.

This paper discusses the experimental approach used to evaluate the heat transfer performance in accordance with the direction of the inlet and outlet of the air in the horizontal storage module.

2. Heat Transfer Test

2.1 Description of the Test Model

The heat transfer test model is a one-half scale model of the real horizontal storage module. Fig. 1 shows the cross section of the thermal test model. The lid of the canister has 24 holes for electrical heaters and 24 holes for thermocouples.

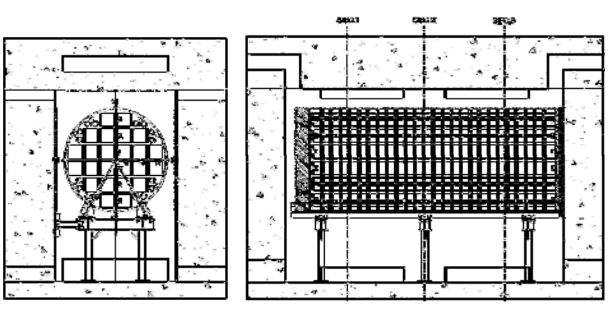

Fig. 1. Cross Section of Heat Transfer Test Model.

The electric heaters, which are to simulate 24 PWR spent fuel assemblies, are accommodated within the baskets and fixed on the top of the lid of the canister by means of the swage lock.

2.2 Heat Transfer Mode and Measurement System

Heat is generated by the spent fuel assemblies within the canister and it is transferred to the surface of the canister via conduction, convection, and radiation. This heat is transferred from the surface of the canister to the inner surface of the module through convection and radiation. The module is designed to dissipate the heat from the canister through the passive heat removal system. This mechanism is a natural convective air flow through the area between the canister and the inner surface of the module. Therefore, the heat transfer from the module to the ambient atmosphere is accomplished through two mechanisms; the heat, which is conducted through the module body, dissipated from the exterior surface of the module to the ambient atmosphere by convection and radiation, and the air, which is heated in the annular area, is vented to the ambient atmosphere through outlet of the passive heat removal system.

The heat transfer from the exterior surface of the module to the ambient atmosphere is [1]

$$q_s = hA(T_s - T_a) + \sigma\varepsilon A(T_s^4 - T_a^4)$$

where q_s is the heat transfer from the exterior surface of the module to the ambient atmosphere, h is a natural convective heat transfer coefficient, A is a surface area, T_s is the temperature at the surface, T_a is an ambient temperature, σ is the Stefan-Boltzmann constant and ε is the emissivity.

The heat transfer to the ambient atmosphere through outlet of the passive heat removal system is [2]

$$q_A = \dot{m} C_p \Delta T$$

where q_A is the heat transfer to the air, $\dot{m}$ is the mass flow rate, C_p is the specific heat of the air and △T is the differential air temperature from the inlet to the outlet.

In order to evaluate the heat transfer characteristics of the horizontal storage module, accordingly, two measurement systems were used in the heat transfer test. One is the temperature data acquisition system, which consists of the thermo-couple scanner, the signal conditioner, the A/D converter and the P/C. The other is the velocity data acquisition system, which consists of the anemometer scanner, the data logger, the A/D converter and the P/C.

2.3 Heat Transfer Test

The horizontal storage module must ensure that the temperatures of the spent nuclear fuel assemblies are maintained within the allowable values during the storage. Therefore, the horizontal storage module must be designed including heat removal capabilities with an appropriate reliability. However, the thermal conductivity of concrete is not good. Therefore, a passive heat removal system was designed so that the temperatures of the fuel assembly cladding material and the horizontal storage module components remain within the allowable limits.

The heat transfer tests were carried out for two cases. In the first case, the passive heat removal system consists of two inlets and two outlets in both sides, respectively. In the second case, it consists of one inlet and one outlet in front and rear side, respectively.

As shown in Fig. 2, the heat transfer tests were carried out in a test house with dimensions of 5.0 m x 6.0 m x 5.0 m. The test house was made of a sandwich panel to decrease the influence of a fluctuation of the ambient temperature. Total heat power from the 24 electric heaters was applied to 4.5 ㎾.

Fig. 1 shows the measuring points of the temperature in the test model. A total of 127 thermocouples were installed: 91 to measure and monitor the temperature of the test model and 36 to measure and monitor the ambient temperature of the thermal test structure.

The sensor to measure the air velocity at the inlet and outlet was two types. Hot wire anemometers were used to measure the air velocity at the inlet duct. As the temperature exhausting from the outlet duct is very high, the air velocity at the outlet duct was measured with vane type anemometers.

Fig. 2. Test Model and Test House.

2.4 Test Results and Discussion

Table 1 lists the maximum temperatures measured under normal conditions. Thermal equilibrium of the test model was reached after about 120 hours, and that state was maintained for a period of 2 days. The average ambient temperature in the house was maintained at approximately 23 °C in the first case and 27 °C in the second case during the normal conditions test.

In the first case, the average temperature at the inlet and outlet was measured at 23 °C and 41 °C, respectively. The average velocity at the inlet and outlet was measured at 0.31 m/s and 0.75 m/s, respectively. Therefore, the mass flow rate of the air was calculated to be 0.0575 ㎏/s. Accordingly, the heat transfer rate to the ambient atmosphere by the air was estimated as 91.8 % of the heat transferred from the horizontal storage module to the environment. This shows that the passive heat removal system was designed well and worked adequately.

In the second case, the average temperature at the inlet and outlet was measured at 27 °C and 53 °C, respectively. The average velocity at the inlet and outlet was measured at 0.25 m/s and 0.68 m/s, respectively. Therefore, the mass flow rate of the air was calculated to be 0.0809 ㎏/s. Accordingly, the heat transfer rate to the ambient atmosphere by the air was estimated as 91.7 % of the heat transferred from the horizontal storage module to the environment. Therefore, the direction of the inlet and outlet of the air has no effect on the heat transfer performance.

Table 1. Summary of the Thermal Test Results

Temp(°C) / Case		Basket	Canister	Module		Amb.
				Inside	Outside	
1st	Sec. I	187	114	43	31	23
	Sec.Ⅱ	216	127	46	33	
	Sec. III	204	124	44	34	
2nd	Sec. I	190	119	47	35	27
	Sec.Ⅱ	218	132	49	36	
	Sec. III	206	128	48	38	

3. Conclusion

The heat transfer performance was evaluated by varying the direction of the inlet and outlet in the horizontal storage module. The main results were as follows:

ⅰ) A temperature difference between the 1st case and the 2nd case did not occur. Therefore, the direction of the inlet and outlet of the air has no effect on the heat transfer performance.

ⅱ) The heat transfer rate transferred to the ambient atmosphere by the air reached 92 %. Accordingly, the passive heat removal system of the horizontal storage module was designed well.

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