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Thermal Test in accordance with Mesh Size at Opening of the Inlets and Outlets of Concrete Storage Cask

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1. Introduction

A concrete storage cask containing 21 spent fuel assemblies is under development by the KOrea RADioactive waste agency (KORAD) in Korea. The temperatures of the spent nuclear fuel assemblies must be maintained within the allowable values under normal and off-normal conditions, and during an accident. Therefore, the concrete storage cask must be designed to have heat removal capabilities with appropriate reliability. However, the thermal conductivity of concrete is not adequate for this purpose. The American Concrete Institute standard ACI-349 specifies a limit of 66 °C for the normal operating temperature of concrete, except for the local areas, which may not exceed 93 °C, and a short-term or accident temperature limit of no more than 177 °C [1]. Therefore, a passive heat-removal system was designed to maintain the temperatures of the fuel-assembly cladding material and concrete storage cask components within these allowable limits. The passive heat-removal system consists of four inlets and four outlets, and their openings are covered by screens of mesh structure to prevent debris or wildlife from entering the ventilation ducts. Depending on its mesh size, each screen will have a different effect on the heat removal of the concrete storage cask.

This paper discusses the experimental approach used in the present study to evaluate the heat removal performance under normal conditions in accordance with the mesh size of the screen installed at the opening of the inlets and outlets.

2. Thermal Test

2.1 Description of the Concrete Storage Cask

The concrete storage cask system consists of three separate components: an over-pack, a canister, and a transfer cask.

Figure 1 shows a schematic of the concrete storage cask. The structural casing of the over-pack is made of carbon steel, and the inner cavity of the casing is filled with concrete, which acts as a radiation shield. The outer diameter of the concrete storage cask is 3,306 mm and its overall height is 6,180 mm. It weighs approximately 148 tons. The concrete storage cask accommodates 21 PWR spent fuel assemblies with a burn-up of 45,000 MWD/MTU and a cooling time of 10 years. The decay heat from the 21 PWR spent fuel assemblies is 16.8 kW.

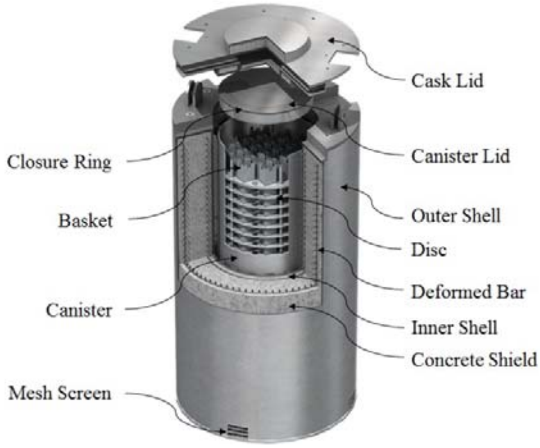

Fig. 1. Configuration of Concrete Storage Cask

2.2 Thermal Test

Thermal tests were performed to evaluate the heat removal performance in accordance with the mesh size of the screen installed at the opening of each inlet and outlet under normal conditions. The thermal tests were carried out for four cases, as shown in Table 1, where each case represents a different combination of mesh size, wire diameter, mesh opening, and percentage of open area.

Table 1. Bird-screen Mesh Specifications

Case	Mesh Size	Wire Dia. (mm)	Opening (mm)	Open Area (%)
1st	#6	0.71	3.53	69.6
2nd	#4	0.71	5.64	78.9
3rd	#8	0.71	2.46	60.2
4th	#12	0.71	1.40	43.6

2.3 Test Results and Discussion

The thermal test for the 1st case was performed by applying a mesh size of #6 used in the Hi-Storm 100 storage cask. Table 2 lists the maximum temperatures measured under normal conditions for the 1st case. The thermal equilibrium of the test model was reached after about 216 h, and that state was maintained for a period of two days. The average ambient temperature in the test house was maintained at approximately 10 °C during the thermal test. As shown in table 2, the maximum temperatures of the canister surface, over-pack inner surface, center of the concrete, and over-pack outer surface were measured as 123, 45, 31, and 23 °C at level 6, respectively.

Table 3 lists the temperatures and velocities measured at the inlet and outlet openings under normal conditions for the first case. The difference in temperatures between the inlet and the outlet openings was found to be considerably large. The average temperatures at the inlet and outlet openings were 9 and 59 °C, respectively, and the average velocities at the inlet and outlet openings were 0.39 and 0.64 m/s, respectively. The average temperature on the over-pack outer surface was 20 °C. Therefore, the mass flow rate of the air was calculated to be 0.253 kg/s. Accordingly, the heat transfer rate by air to the ambient atmosphere was estimated to be 75.4 % of the heat transferred from the concrete storage cask to the environment.

Table 2. Thermal test results in the first case

Level (mm)	Temperature (°C)				Ambient (°C)
	Canister Surface	Over-pack			
		Inner Surface	Concrete Center	Surface	
6(4,970)	123	45	31	23	10
5(4,630)	118	44	30	21	
4(4,130)	113	41	28	20	
3(3,630)	108	38	26	19	
2(2,630)	102	31	21	15	
1(1,630)	85	23	16	13	

Table 3. Temperature and velocity at the inlet and outlet

	Inlet			Outlet		
	0°	90°	180°	45°	135°	225°
Temp. (°C)	9.3	8.7	9.1	55.3	59.2	61.6
Velo. (m/s)	0.29	0.47	0.42	0.68	0.63	0.67

Table 4 lists the maximum temperatures measured at level 6 under normal conditions for all four cases. The maximum temperatures of the canister surface were 123, 131, 139, and 140 °C in the first, second, third, and fourth cases, respectively. Assuming that the maximum ambient temperature was 26 °C, the maximum temperatures of the canister surface could be considered as 139, 137, 139, and 140 °C in the first, second, third, and fourth cases, respectively. Accordingly, it can be deduced that the temperature difference at the canister surface would have reached a value between 1 and 3 °C. Therefore, the mesh size of the screen was estimated to have an insignificant effect on the temperature rise of the canister surface.

The temperature difference in the over-pack body became smaller than the difference in ambient temperature because of thermal mass. However, when the ambient temperature difference was considered for simplicity, the temperature difference on the over-pack inner surface was between 1 and 5 °C, and the temperature difference in the center of the concrete was between 2 and 4 °C. The mesh size of the screen was estimated to have an effect on the temperature rise of the components of the over-pack body, but the temperature difference on the over-pack surface appeared to be minimal. Therefore, the mesh size of the screen was estimated to have a similarly insignificant effect on the temperature rise of the over-pack surface compared to the canister surface.

The heat transfer rates to the ambient atmosphere by convective airflow through the passive heat removal system of the concrete storage cask were estimated as 75.4 %, 84.8 %, 74.9 %, and 68.8 % in the first, second, third, and fourth cases, respectively. Therefore, as the mesh size of the screen decreased, the heat removal by the natural convection cooling through the passive heat removal system was reduced, and the temperature of the concrete storage cask rose.

Table 4. Comparisons of temperature at level 6

Location (mm)	Temperature (°C)				Ambient (°C)
	Canister Surface	Over-pack			
		Inner Surface	Concrete Center	Surface	
1st Case	123	45	31	23	10
2nd Case	131	54	39	31	20
3rd Case	139	63	47	39	26
4th Case	140	65	49	39	26

3. Conclusion

Thermal tests were carried out to evaluate the heat removal performance in accordance with the mesh size of the screen installed at the opening of the inlets and outlets under normal conditions.The main results of the study are described below.

(i) The mesh size of the screen had an insignificant effect on the temperature rise of the canister surface and the over-pack surface. However, it had a considerable effect on the temperature rise of the components of the over-pack body.

(ii) The heat removal by the natural convection cooling through the passive heat removal system was reduced for screens with smaller mesh sizes, and the temperature of the concrete storage cask rose.

REFERENCES

[1] ACI 349-13, Code Requirements for Nuclear Safety-Related Concrete Structures(ACI 349-13) and Commentary, American Concrete Institute, Appendix E.4, 2013.