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Thermal Analysis of a Module Storage System for Spent Nuclear Fuel

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1. Introduction

The purpose of a thermal analysis is to ensure cooling capability of module storage system in order to predict the maximum temperature of concrete and fluid. The spent fuel should be protected from degradation during store period that leads to a gross fuel rupture. The fuel cladding temperature limit of the dry storage is typically below 380℃ for a 5-year cooled fuel assembly for normal operations and minimum 20 years storage. The fuel temperature should also generally be maintained below 570℃ for the short-term off-normal and accident conditions. The decay heat removal system is designed by passive or an active cooling system for the dry storage of the spent fuel. A modular storage system was proposed as part of the effort[1]. A modular storage system is a canister-based spent nuclear fuel dry storage system that consists with three or seven canisters. In this study, thermal performance evaluation carried out with computational fluid dynamics(CFD) code to estimate temperature of concrete overpack, canister structure and air according to NUREG-2152[2] as additional guidance on the use of CFD. Thermal analyses of ventilation system have been carried out for the determination of the optimum inlet and outlet duct height. The computational fluid dynamics code ANSYS CFX 17 was used for the thermal analysis of modular storage system.

2. Methods and Results

2.1 Description of modular storage system

A cylindrical modular type dry storage system is intended to safely store of spent nuclear fuel from pressurized water reactors using dry storage method, similar to traditional dry storage system, but also to increase the storage capacity as much as possible and minimize the required storage area. The general design of the cylindrical modular dry storage system are shown in Fig. 1. The cylindrical dry storage system consists of the body structure, lid, canister for loading the spent nuclear fuel, eight inlets on the bottom, and eight outlets on the top. The main body forms the entire structure with reinforced concrete, protecting the canister inside and shielding radiation from internal spent nuclear fuel. Seven canisters are designed to maintain containment by loading the spent nuclear fuel (24 assemblies) from PWR. Air inlet and outlet are for cooling of natural convection in accordance with the requirements of domestic and international dry storage regulations for application of the passive cooling system.[3]

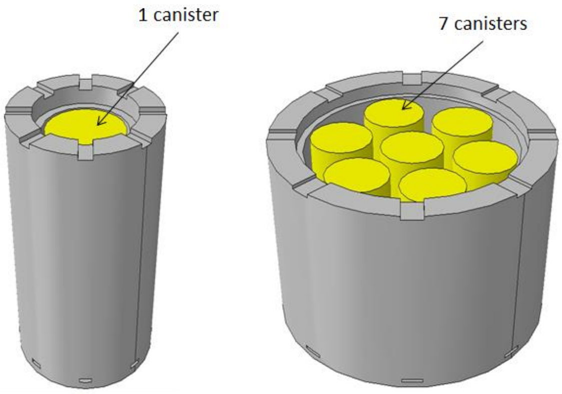

Fig. 1. General design of topical storage cask and 7-casnistered modular type storage system

2.2 CFD Model

The CFD thermal model focus on the calculation for canister, concrete overpack, lid, and air cooling temperatures. A three-dimensional (3D) CAD model of a modular storage system was created based on the geometry information of patent description. 3D analytical geometry using a 1/4 symmetry, as shown in Fig. 2 was used to evaluate temperatures. Based on the 3D CAD model for fluid and solid domains, meshes were created using ANSYS Workbench mesh-generation tool. Tetrahedral meshes were generated in the fluid domain, excluding the boundary-layer region in air flow.

2.3 Boundary Conditions

The main components of the dry storage system are the canister storing spent nuclear fuel and the concrete overpack for radiation shielding and heat removal. The main materials of the canister and overpack structure consist of stainless steel and concrete. Thermal properties for thermal analysis of dry storage containers, such as thermal conductivity, specific heat and density, are referred by matweb site. Boundary conditions for the CFD analysis were determined based on the operating conditions of the dry storage systems. The most significant thermal design feature of the dry storage system is the passive convective air flow around the outside of the canisters. Cool ambient air enters the bottom inlet regions and is heated as it flow past canisters and out the upper outlet regions. The storage canister is assumed to store 24 PWR spent fuel assemblies with a burn-up of 45,000 MWD/MTU and a cooling time of 10 years. Supplied air temperature is 38℃ and the decay heat load of canister from the 24 PWR assemblies is 17.6 kW. Inlet and outlet boundary are considered by pressure boundary with non-differential pressures.

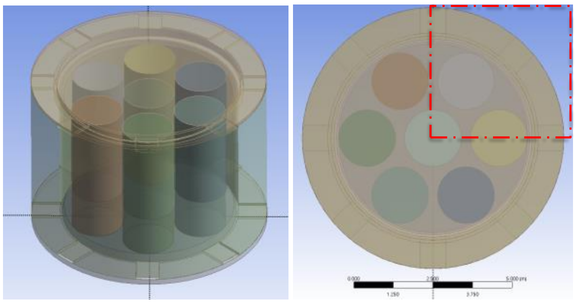

Fig 2. The CFD analysis geometry of the modular storage system

2.4 Analysis Results

Figure 3 shows temperature contours of cylindrical modular dry storage systems except canisters. Maximum temperature of air is 220℃ around canister surfaces. On the other hand, local maximum temperature of concrete overpack is only about 92℃. Figure 4 shows heat transfer as a function of hydraulic diameters of inlet and outlet. The heat transfer(Q) is calculated based on mass flow rate(m), specific heat(Cp) and differential temperature(ΔT) between inlet and outlet region as follows:

$$Q = m \times Cp \times \Delta T$$

When the hydraulic diameter are increased, the heat transfer increases. However, for 0.3 and above, heat transfer increases due to hydraulic diameter increases begin to be significantly reduced. It appears that heat transfer is nearly maintained in the vicinity of 0.35 as hydraulic diameter increases. Therefore, it can be seen that hydraulic diameter has little effect on heat transfer growth when hydraulic diameter reaches 0.35 or higher.

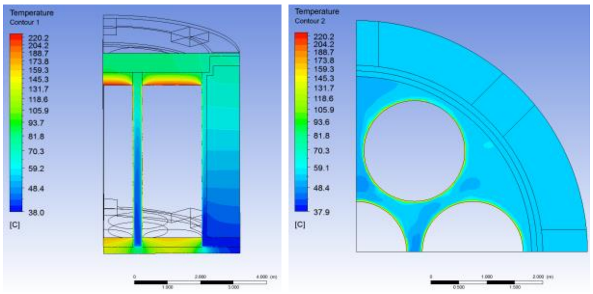

Fig 3. Temperature contours of fluid and solid regions.

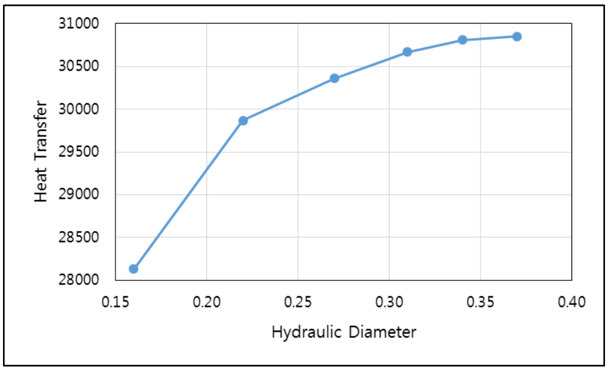

Fig 4. Heat transfer as a function of hydraulic diameter in inlet and outlet.

3. Conclusions

In this study, thermal performance evaluation carried out with ANSYS CFX, commercial CFD code, to estimate temperature of concrete overpack, canister structure and air. The purpose of this assessment is to derive the area of inlet and outlet for storing a number of canisters. As a result of thermal analysis, the hydraulic diameter has a significant impact on the heat transfer. When the hydraulic diameter are increased, the heat transfer increases. However, hydraulic diameter has little effect on heat transfer growth when hydraulic diameter reaches 0.35 or higher. The evaluation of the local heat distributions of canister and its internal helium circulation are necessary.

REFERENCES

[1] Sunghwan Chung. "Cylindrical Modular Type Dry Storage System and method for Pressurized Water Reactor Spent Nuclear Fuel." Korea Patent No. 1015997440000. 26 Feb. 2016..

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[3] IAEA, “Storage of Spent Nuclear Fuel”, IAEA Safety Standards for protecting people and the environment, Specific Safety Guide No. SSG-15, IAEA. 2012.