THERMAL PERFORMANCE EVALUATION OF CYLINDRICAL MODULAR TYPE DRY STORAGE SYSTEM FOR PWR SPENT NUCLEAR FUEL USING CFD CODE

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ABSTRACT

A **c**ylindrical **mo**dular type **d**ry **s**torage(CMODS) system is a canister-based spent nuclear fuel(SNF) dry storage system. In order to guarantee fuel rod integrity, it need to research focus on cladding degrading mechanisms such as creep and hydrogen reorientation, which are strongly influenced by temperature. Therefore, dry storage system has to ensure cooling performance of fuel assemblies under any circumstances such as normal, off-normal and accident conditions. It is important to evaluate the temperature of cylindrical modular dry storage system because a large number of SNF are stored in this module compare with another storage cask systems. In this study, thermal performance evaluation carried out with computational fluid dynamics(CFD) code to estimate temperature of concrete overpack, canister structure and fuel assemblies according to NUREG-2152 as additional guidance using CFD. The purpose of this assessment is to derive the area of inlet and outlet for storing a number of canisters. According to the result, the spent fuel is allowed to cool under a limiting temperature to avoid a fuel failure. It would be of great intent to investigate the maximum fuel temperature of concrete overpack in a dry storage system. The present paper deals with the thermal hydraulic characteristics of spent fuel for a dry storage system using the CFD method.

1. INTRODUCTION

Dry storage systems are used in many countries to store SNF. Most of these dry storage systems are intended for interim storage prior to final disposal or reprocessing. The government of Republic Korea is also considering dry storage systems in on-site of nuclear power plant to store SNF before interim storage. Accordingly, power generation operators are working to establish efficient on-site dry storage systems. A CMODS system has been proposed to improve economic efficiency[1]. A CMODS system is a canister-based SNF dry storage system that consists with seven canisters. In order to guarantee fuel rod integrity in CMODS systems, it need to research focus on cladding degrading mechanisms such as creep and hydrogen reorientation, which are strongly influenced by temperature. According to NUREG-1567, the NRC accepts temperature range between 66°C and 149°C occurring in normal and off-normal conditions by requirements of ACI 349. If concrete temperatures of local areas do not exceed 93°C in normal or off-normal conditions, tests to prove capability of the concrete for temperatures or reduction of concrete strength used for design are not required. Therefore, dry storage system has to ensure cooling performance of concrete overpack under any circumstances such as normal, off-normal and accident conditions. It is important to assess the temperature of a CMODS system because this module stores large numbers of SNF compared to other storage container systems. Thermal performance for a CMODS was evaluated by computational fluid dynamics(CFD) code, ANSYS CFX 17, to estimate concrete overpack, canister structure and air temperatures according to NUREG-2152[2] as additional guidance on the use of CFD. Thermal analysis of ventilation system have been carried out for the determination of the optimum inlet and outlet duct dimension.

2. CHARACTERISTICS OF CMODS SYSTEM

2.1 Description of the CMODS System

A CMODS system is intended to safely store of SNF 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 CMODS system are shown in Fig. 1. The CMODS system consists of the body structure, lid, canister for loading the SNF, 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 SNF. Seven canisters are designed to maintain containment by loading the SNF (24 assemblies) from PWR. The air inlet and outlet are designed as passive natural convection cooling systems according to domestic and international dry storage regulations.[3]

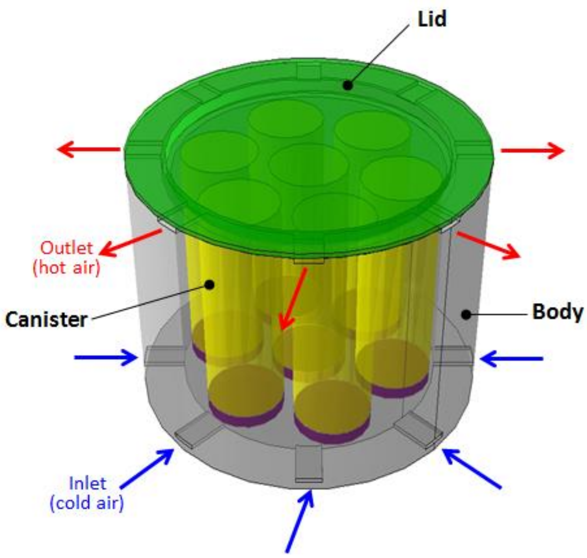

Fig 1. 7-canistered CMODS system

2.2 CFD Model

The CFD thermal model focuses on the calculation for canister, concrete overpack, lid, and air-cooling temperatures. A three-dimensional (3D) CAD model of a CMODS 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 airflow. The RNG k–ε model was used for the simulation of turbulence, because this model has shown better results with respect to swirl flows, when compared with other two-equation models. Even if the RSM model has good accuracy in circular curved channel flow, the RNG k–ε model can reduce calculation time while retaining a similar analysis accuracy. It is, therefore, quite reasonable to use the RNG k–ε model with full buoyancy effects for the evaluation of heat removal performance by air.

2.3 Material Properties and Boundary Conditions

The main components of the dry storage system are the canister storing SNF 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 listed in Table 1, 2 and 3. 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.

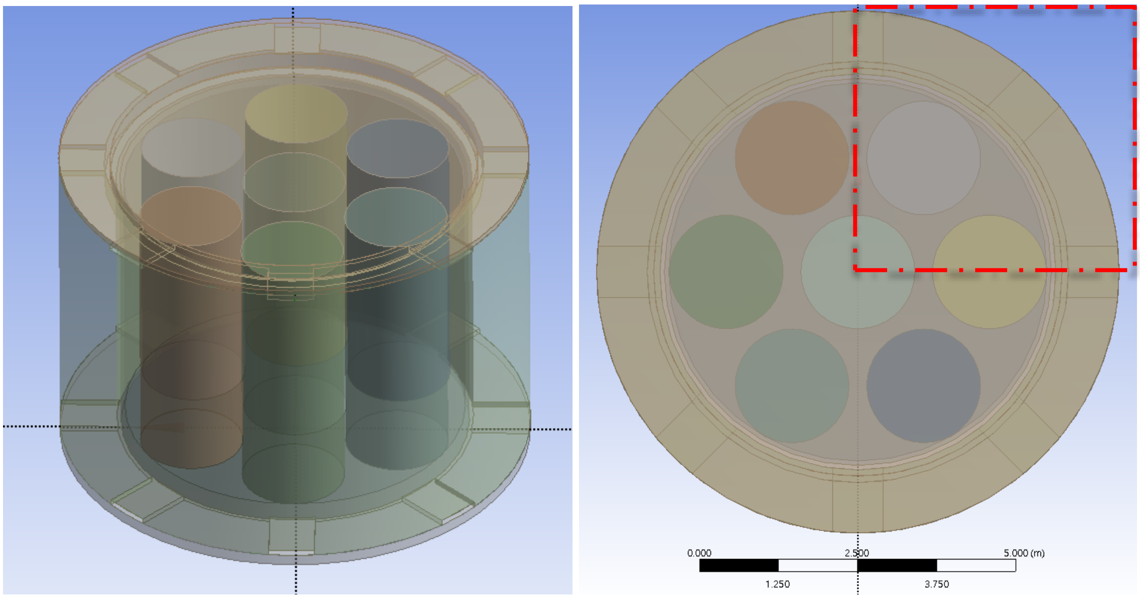

Fig 2. The CFD analysis model of CMODS system

Table 1. Thermal properties of concrete

Temperature [°C]	37.8	93.4	260.1	537.8
Density [kg/㎥]	2307			
Specific heat [J/kgK]	1046.7			
Thermal conductivity [W/mK]	2.07	1.90	1.73	1.38

Table 2. Thermal properties of air

Temperature [°C]	27	127	227	327	527
Density [kg/㎥]	1.1614				
Specific heat [J/kgK]	1007	1014	1030	1051	1099
Thermal conductivity [W/mK]	0.0263	0.0338	0.0407	0.0469	0.0573

Table 3. Thermal properties of stainless steel

Temperature [°C]	20	100	300	500	700
Density [kg/㎥]	8030				
Specific heat [J/kgK]	472.6	499.4	541.7	563.1	581.9
Thermal conductivity [W/mK]	14.8	16.2	19.4	22.2	25.0

3. ANALYSIS RESULTS

Figure 3 and 4 shows temperature contours of cylindrical modular dry storage systems except canisters. Maximum temperature of air is 220°C around canister surfaces. On the other hand, local maximum temperature of concrete overpack is only about 92°C. Figure 5 shows velocity vector and flow streamline of air. Maximum air velocity is 3.95 m/s at inlet and outlet region. Air has a higher flow velocity near surface of canisters than surface of concrete overpack. It is because the drive force of the air flow is the heat transfer from the surface of canister. Figure 6 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. For 0.3 and above, heat transfer increases due to hydraulic diameter increases begin to be significantly reduced. Heat transfer reaches to the steady state if hydraulic diameter is over 0.35.

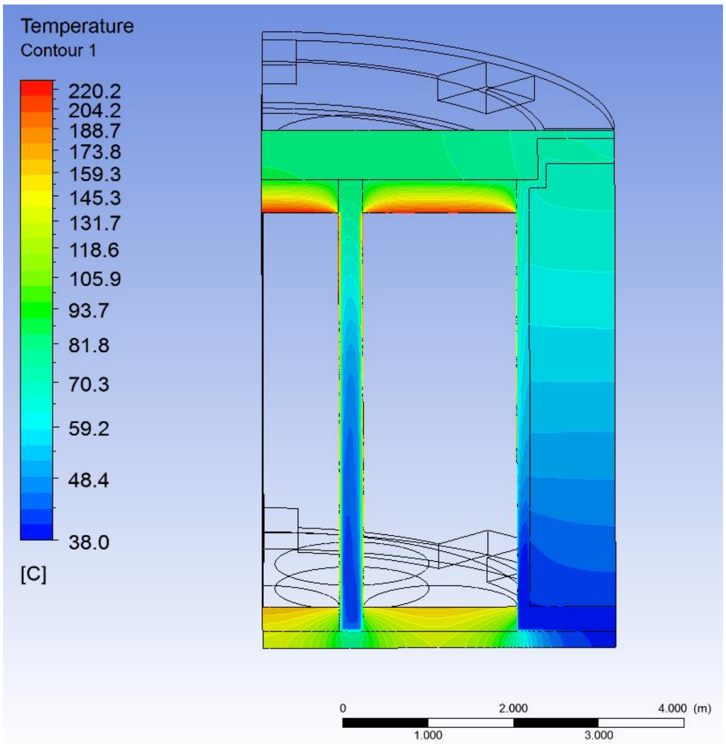

Fig 3. Vertical Temperature contours of CMODS.

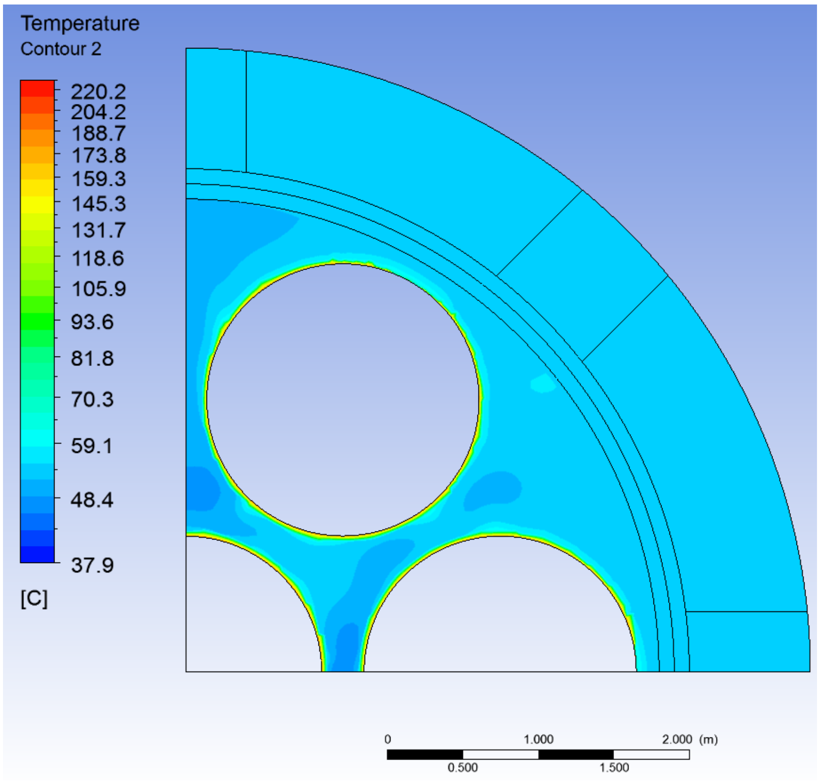

Fig 4. Horizontal Temperature contours of CMODS.

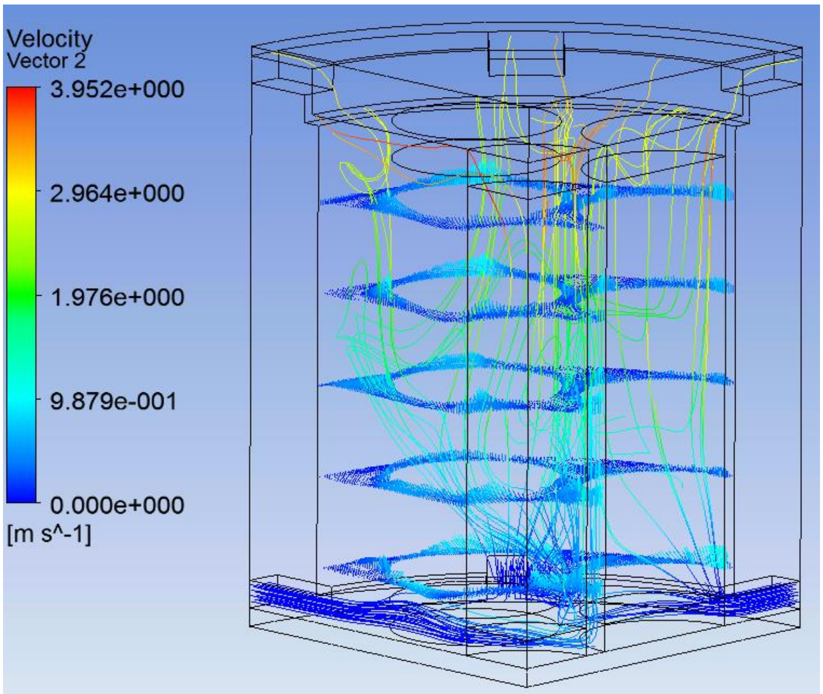

Fig 5. Velocity vector of coolant air

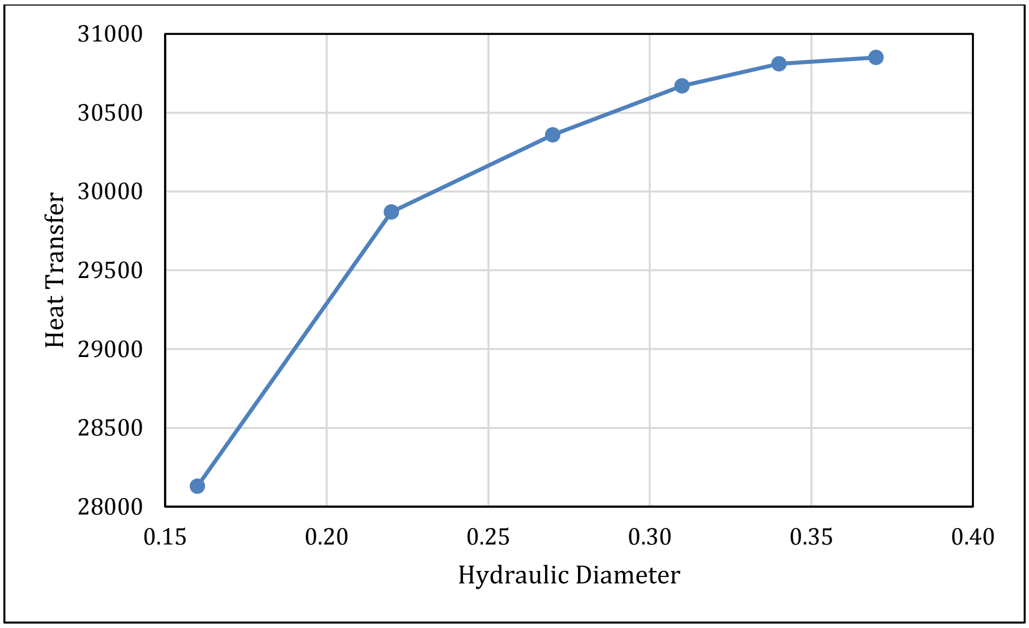

Fig 6. Heat transfer between inlet and outlet. .

4. CONCLUSIONS

Maximum temperatures of air around canister surfaces and concrete overpack are 220°C and 92°C, respectively. Maximum concrete overpack temperature is below temperature limits of US NRC's NUREG-1567.

The heat transfer increases as hydraulic diameter are increased. However, hydraulic diameter has little effect on heat transfer growth when hydraulic diameter reaches 0.35 or higher. Therefore, duct's hydraulic diameter of cylindrical modular type dry storage system should be over 0.35 to satisfy temperature requirements of concrete.

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