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# CFD Simulation of Spent Fuel in a Dry Storage System

Young Kyun Kwack [a], Wang Kee In [*a], Chang Hwan Shin [a], Tae Hyun Chun [a], Dong Hak Kook [a]
[a]KAERI, 989-111 Daedeok-daero, Yuseong-gu, Daejeon 305-353, Republic of Korea
[*]*Corresponding author: wkin@kaeri.re.kr*

## 1. Introduction

The spent fuel pool is expected to be full in few years. It is a serious problem one should not ignore.

The dry storage type is considered as the interim storage system in Korea. The system stores spent fuel in a storage canister filled with an inert gas and the canister is cooled by a natural convection system using air or helium, radiation, and conduction. The spent fuel is heated by decay heat. The spent fuel is allowed to cool under a limiting temperature to avoid a fuel failure. Recently, the thermal hydraulic characteristics for a single bundle of the spent fuel were investigated through a CFD simulation [1].

It would be of great interest to investigate the maximum fuel temperature 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.

## 2. Numerical Simulation

### *2.1 Numerical model of the dry storage system*

The dry storage system is composed of 32 bundles as shown in Figure 1. In a situation in which the dry storage system is not determined, it is selected in the preliminary computational problems because it is one of the system aggregate entering lots in the existing system.

Using a quadrilateral dominant mesh, 3.8 million nodes were used. Each rod bundle was modeled using a porous media approach. The pressure loss coefficient of the rod bundle was set to 5.875 /m. A volumetric porosity of 0.5583 is thus defined in the Navier-Stokes equations for the porous media to simulate the acceleration of the flow due to mass conservation considerations. The boundary conditions of the external wall are a no slip wall condition with a constant temperature of 320 K. The heat source in the porous media is 9.06 kW/m$^3$ because the decay heat of the spent fuel is assumed to be about 1.6 kW/FA(0.01 % of power). Gravity was also considered and The P1 radiation model was used.

A numerical model for the dry storage system was studied using the commercial CFD code CFX ver. 14.0. A three dimensional steady-state analysis was carried out through parallel computations. The convergence criteria required that a residual of $10^{-6}$ or less be obtained at all nodes for each of the equations solved.

### *2.2 Model of full assembly for a single bundle*

The total length of the computational domain is 4,082 mm. Using a hexahedral type trimmer mesh with a prism layer, almost 0.2 billion grid points were generated, as shown in Fig. 2.

The inlet boundary conditions are applied to the bottom of the domain. They have a uniform velocity (0.33 m/s) and temperature (402.6 K) given from the results of the dry storage system. The outlet boundary condition has a relative pressure of 0.0 Pa at the top surface and a symmetric boundary condition is specified for the side walls. On the fuel surface, the heat source (56 W/m$^2$) is applied. All other wall boundary conditions are considered to be adiabatic. Helium at 300 K was used as the working fluid. Gravity is also considered and the S2S radiation model is used.

A commercial computational code STAR-CCM+ Ver. 8.02 was used in the current study. The convergence criteria required that a residual of $10^{-4}$ or less be obtained at all cells for each of the equations solved by the parallel computation of 138 cores.

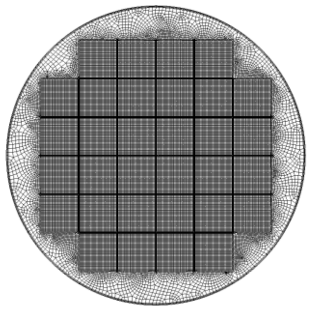

Fig. 1. Cross sectional grids of dry storage system.

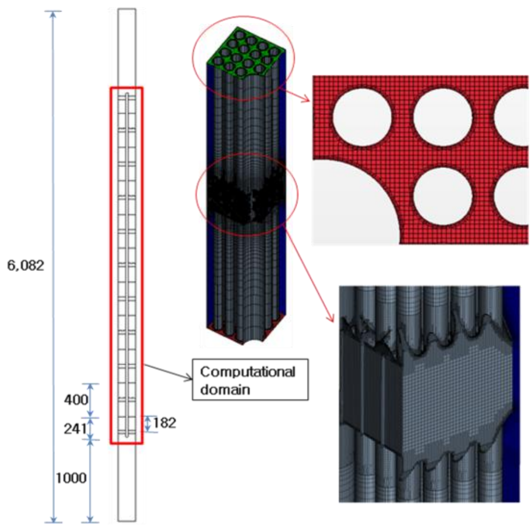


Fig. 2. Computational domain and grids of full assembly for a single bundle with 16×16 rod.

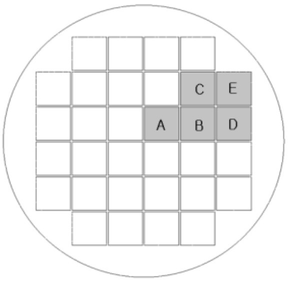


Fig. 3. A symbol of each bundle.

Table 1: Temperature and velocity of each bundle

| | Inlet | | Middle | | Outlet | |
|---|---|---|---|---|---|---|
| | T[K] | V[m/s] | T[K] | V[m/s] | T[K] | V[m/s] |
| A | 402 | 0.35 | 482 | 0.54 | 514 | 0.24 |
| B | 414 | 0.37 | 481 | 0.55 | 511 | 0.27 |
| C | 419 | 0.30 | 479 | 0.46 | 508 | 0.28 |
| D | 424 | 0.22 | 477 | 0.24 | 505 | 0.28 |
| E | 424 | 0.19 | 551 | 0.19 | 502 | 0.26 |

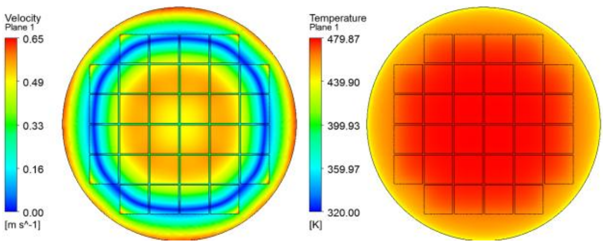


Fig. 4. Velocity and temperature contour of the dry storage vessel with radiation.

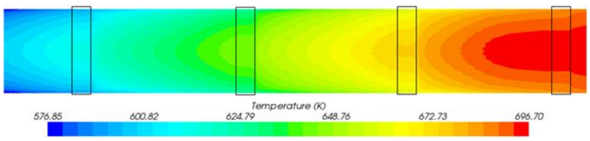


Fig. 5. Temperature contour of the side wall.

## 3. Results

Fig. 3 shows a symbol of each bundle. The temperature and velocity of each bundle are shown in Table 1. The inlet temperature of the outer bundle was higher because of a temperature increase from natural convection. In the contrast with the inlet, the inner bundle temperature is higher at the outlet. There is a stagnation region at the middle of the outer bundle as shown in Fig. 4.

A 3D thermal flow simulation for a single fuel assembly was carried out. The simulation of a single bundle used the values given from the results of a dry storage system. As shown in Fig.5, the temperature heating from the decay heat of spent fuel was spread out by a spacer grid. The axial velocities at the corners of the fuel assembly were the fastest, as shown in Fig. 6. These result in a decrease in temperature, as shown in Fig. 7. In contrast, the temperature of the center fuel assembly was higher than elsewhere.

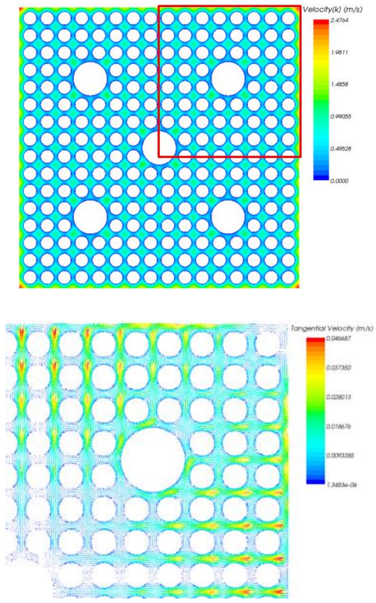


Fig. 6. Axial velocity and vector distributions downstream of 9th-spacer grid.

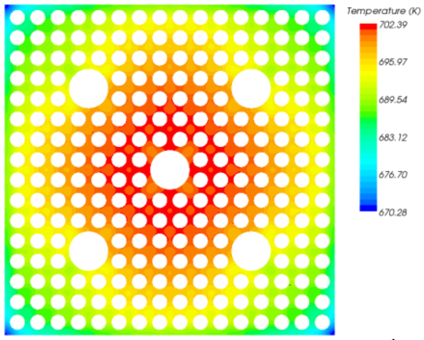


Fig. 7. Temperature distribution downstream of 9th-spacer grid.

## 4. Conclusions

A 3-D thermal flow simulation was carried out to predict the temperature of spent fuel. A dry storage system composed of 32 fuel bundles was modeled. The inlet temperature of the outer bundle is higher and that of inner bundle, however, is higher at the outlet. In a single fuel assembly, a center temperature of the fuel assembly was higher than elsewhere.

## Acknowledgements

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## REFERENCES

[1] W. K. In, C. H. Shin, T. H. Chun, K.W. Song and J.W. Choi, CFD Simulation of Thermal Flow in PWR Spent Fuel Test Apparatus for the Dry Storage, Korean Radioactive Waste Society 2010 Autumn Conference, pp.383-384, 2010.