Numerical Analysis on Natural Convection of Backfill Gases in a Dry Storage System for Spent Nuclear Fuels

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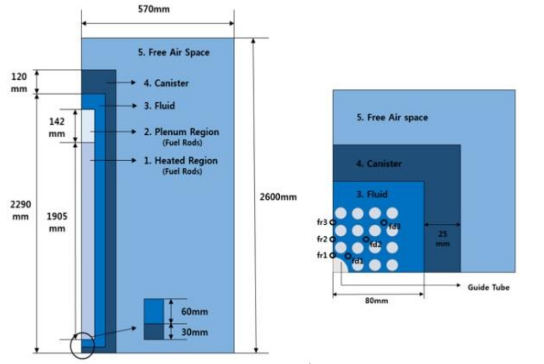
1. Introduction

Dry storage systems cool down spent nuclear fuels passively, depending on the natural convection of backfill gases filled in the storage cask. As the representative backfill gases, there are helium, air nitrogen, and argon. This study was devised to investigate the characteristics of natural convection of the backfill gases and compare their cooling capability for spent nuclear fuels.



(a) (b)

Fig. 1. (a) side view, (b) top view of modeled geometry.

2. Numerical Analysis

The numerical modeling of the dry storage system was performed with Ansys Fluent software 14.0. For the modeling, some assumptions were taken into account. First, the system height was downscaled by a ratio of 1/2. Second, the assembly containing 8×8 spent nuclear fuel rods was considered in the system, instead of the full-scaled assembly of 16×16 fuel rods.

Figure 1 shows the side-view and top-view of inner structure of the dry storage system. Region 1 and 2 indicate the heated and plenum region of the fuel rods respectively. Region 3 represents the fluid region where a natural convective flow of backfill gases occurs. Each of region 4 and 5 indicates the canister and free air space. Stainless steel grade 304 (SS304) was used as a canister material. The FD 1, 2, and 3, and FR 1, 2, and 3 present the locations to extract data set in the fluid region. Heated region of the fuel rods was applied with a constant heat flux of 53.83 W/m^2.

3. Results

3.1 Peak Cladding Temperature (PCT)

Cladding surface temperature is an important parameter to estimate the effectiveness of passive heat removal by natural convection of the backfill gases and the integrity of fuel claddings. According to the Table 1 obtained from this study, the PCT increased in the order of nitrogen, air, helium and argon. While the PCT of nitrogen gas is about 433 K, argon is close to 456 K. It implies that the nitrogen shows the best heat dissipation among the four backfill gases.

Table 1. PCT value for each of back-fill gases

Fluid	Helium	Air	Nitrogen	Argon
PCT(K)	447.35	444.46	433.41	455.91

3.2 Axial Direction Reynolds Number Distribution

Figure 2 shows the axial distribution of Reynolds number (*Re*) in the sub-channels of the fuel rods when using air. Except vicinity of the plenum region of the fuel rods, the *Re* values increase in the axial direction. The inertia of the natural convection flow is strongest at z=1.0 for all the sub-channels. Compared to the air, helium showed a very weak axial flow (data not shown). The *Re* of the flows range from 2 to 11. While argon showed a highest *Re* range, nitrogen showed a similar behavior with air but a slightly higher *Re* range.

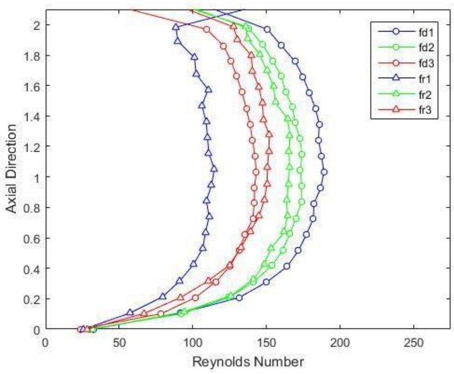


Fig. 2. Axial Reynolds Number distribution along the sub-channels for air.

3.3 Comparison of correlations between the Rayleigh and Nusselt Number

The overall empirical equation between *Nu* and *Ra* was compared with that defined by the Chu & Churchill's vertical wall correlation based on diameter of the canister.

The result with helium (data not shown) does not match very well as the average error was estimated about 67.02%. Argon shows average error of 16.10%, which is much less than helium. But natural convection of the gas was not observed in the subchannels. Air and nitrogen are in good agreement with the correlation with average error of 9.96% and 4.73%, respectively. These results give the conclusion that natural convection flows of air and nitrogen provide a better cooling capacity than helium and argon for spent nuclear fuels.

4. Conclusion

This study investigated the cooling capability of backfill gases in a dry storage system for spent nuclear fuels. The chosen gases are as follows: helium, air, nitrogen, and argon. Among the gases, nitrogen showed largest amount of heat dissipation.

ACKNOWLEDGEMENT

This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP: Ministry of Science, ICT and Future Planning) (No. NRF-2018M2B2A9065822).

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