Experimental Investigation of Temperature Profiles in Spent Fuel Model

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1. Introduction

To ensure the integrity of the zirconium-based alloy cladding, standard review plan for spent fuel dry storage systems (SFDSS) at a general license facility limits the maximum calculated cladding temperature to less than 400℃ for normal conditions of storage and short-term loading operations, including cask drying and backfilling. It also requires that the maximum temperature of the SFDSS concrete (ACI 318) does not exceed 200°F [1]. In order for the design temperature to meet these limits, an accurate temperature calculation tool with appropriate design methodology is required. T.E. Michener developed the COBRA-SFS code and calculated the temperature distribution of fuel and the structure of the SFDSS containing 24 fuel assemblies and verified the code reliability by comparing with the test results [2]. In land, code analyses by using a COBRA-SFS [3] and a test facility setup for code verification are being prepared [4]. In this study, the heat transfer of a spent fuel model was examined experimentally.

2. Experiment

Heat transfer experiment for the PWR spent fuel model was conducted using the STEP(Single Fuel Assembly Temperature Experimental Facility) experimental facility designed by KAERI and manufactured by SE & T (Fig. 1). The STEP consists of a mechanical system, an electric system, a gas backfill system, a data acquisition system, and a fuel assembly model. The mechanical system consists of a fuel tube in the form of a duct, which maintains the assembly model at the outer periphery of that and forms an upward flow path, a pipe shaped cask forming a downward flow path from the outside of the fuel tube, a bottom chamber provided with an electric lead wire passage and a gas backfill valve below the cask, and a top flange with Conaxes that forms a thermocouple pressure boundary at the top of the cask. A 50 cm thick ceramic wool blanket cover the cask to minimize heat loss. The electrical system supplies and controls 179 heater rods. The power is divided into five groups and each group can control independently the power. The power supplied to the assembly model can be controlled in units of 0.01 kW from 0.5 to 3 kW. The gas backfill system fills and discharges the gas by a helium gas cylinder and a vacuum pump connected to a valve installed in the lower chamber. The data acquisition system acquires a total of 190 temperatures by k type thermocouples installed in the 13 heater rods, 3 points in the circumferential direction of the fuel tube and 4 points in the circumferential direction of the cask at each 8 different axial location and 30 points in the upper subchannels.

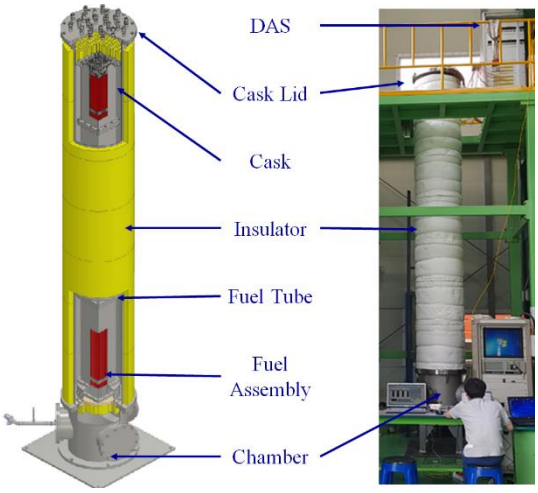

Fig. 1. Test Facility (STEP).

Temperature signals are collected and stored by a laptop equipped with four Keysight 34972a data loggers and Agilent VEE Pro. The fuel assembly model used in the test simulates a spent fuel of Westinghouse 14×14 nuclear fuel assemblies. It consists of 179 heater rods, 16 control rods, and one measuring rod, and consists of seven support grids and upper and lower flow plate simulators. For the heat transfer test at 1 kW power supply condition, the experimental variables are the gas type and the power

distribution type. Vacuum and helium were tested for uniform and non-uniform heat distribution conditions, respectively. For helium backfill, 0.5 kW and 2.0 kW tests are added. The helium pressurization condition is 1.5 bar and the vacuum condition is 75 torr. In case of uniform heat distribution condition, the total 1 kW output was uniformly distributed to the 179 rods. In case of non-uniform heat distribution, 0 output supplied to from rod No. 1 to No. 72, and 1 kW output uniformly distributed for from No. 73 to No. 179.

3. Results and Discussion

Results of 1.0 KW vacuum and helium backfill are presented in Fig. 2. At 1.0 KW uniform distribution, the maximum cladding temperature was 301℃ for vacuum backfill and 233℃ for helium backfill. The temperature distribution varies greatly depending on the backfilled gas. For the vacuum backfill, the peak temperatures are the higher and temperature gradients the steeper than that of the helium, indicating that radiation is the least effective heat transfer mechanism. Helium backfill is evident in enhanced heat transfer due to its high conductivity. The axial profile is flattest. Temperatures of the non-uniform power distribution were larger than those of the uniform distribution, but the difference was not significant.

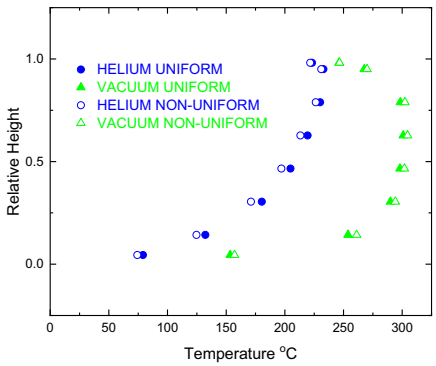

Fig. 2. Temperature Profiles According to Backfill and Power Distribution.

The axial temperature profile at 0.5, 1 and 2 kW output in Helium backfill is shown in Fig. 3. The temperature profiles were similar with the assembly power variation and the maximum temperatures were 143℃, 233℃, and 356℃, respectively.

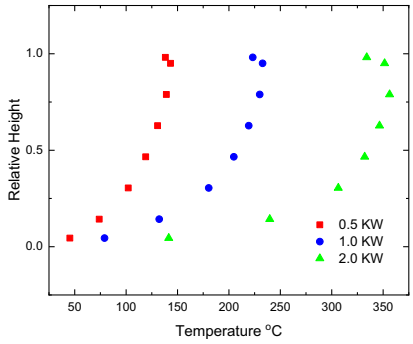

Fig. 3. Temperature Profile According to Power.

4. Conclusions

Temperatures of a 14 × 14 spent fuel model installed in STEP were measured under helium and vacuum backfill. In 1 kW homogeneous power distribution, the maximum cladding temperature was in vacuum backfill. The cladding temperature profile was obviously different according to the backfill gas. Some tests to identify the mechanism of heat transfer under vacuum condition are required as a further work.

ACKNOWLEDGEMENT

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