Measurement Plan of Residual Moisture

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1. Introduction

In order to maintain the integrity of spent nuclear fuel when spent nuclear fuel is stored in the dry storage system, water within the canister is drained, residual moisture in the canister and spent nuclear fuel must be removed, and spent nuclear fuel have to be stored in inert gas atmosphere. Drying equipment is required to remove the residual moisture remaining in the canister of the spent nuclear fuel storage system and spent nuclear fuel. In order to evaluate the amount of residual moisture remaining in the canister after drying the moisture present in the canister of the spent nuclear fuel storage system using the drying equipment, measurement system capable of measuring moisture content should be established. Therefore, the method of measuring the residual moisture according to the vacuum drying and the gas dehydration drying method was analyzed. The residual moisture measuring equipment was investigated and selected, and a schematic diagram of the measurement system for dryness evaluation was derived.

2. Key Parameters for Dryness Evaluation

In the United States, the University of South Carolina, South Carolina State University, University of Florida and AREVA are participating in experiments on vacuum drying and gas dehydration drying method under the Nuclear Energy University Programs (NEUP).

In this program, key conditions for simulating drying of spent nuclear fuel storage system are as follows;

- Vacuum and forced circulation
- Sequence, number, timing of stages in drying process
- Power to simulate decay heat with heater rods
- Ice formation

The main parameters for measuring or evaluating in experiment of this program are “temperature, chamber pressure, gas composition, gas flow rate, water removed as a function of time, indication of ice formation”.

The experiments conducted in this program are as follows;

- Design and fabrication of mock fuel assembly with heater rods and hardware
- Design and fabrication of vacuum chamber
- Testing with small chamber (vacuum and forced circulation)
- Instrument testing (guided wave, IR camera, thermocouples, etc.)
- Optical emission spectrometer (OES) was applied to a small chamber, and experiments were performed to obtain calibration curve as shown Fig. 1 to quantify the moisture content by analyzing the emission spectrum of dry and humid nitrogen under the pressure condition of 3 torr.

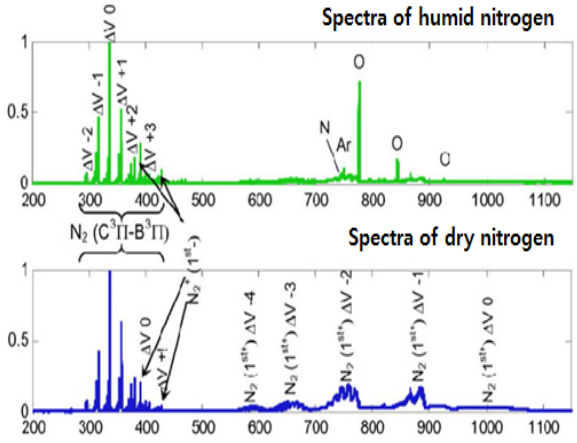

Fig. 1. Spectra of humid and dry nitrogen.

Regarding the evaluation of the integrity of the cladding in the drying of canister, the regulatory requirements for a dry storage system are prescribed as follows;

- Maximum fuel cladding temperature : < 400°C
- Repeated thermal cycling : < 10 cycles with cladding temperature variations more than 65°C
- Pressure : 3 torr for 30minutes (vacuum drying)
- Cold trap temperature : -7°C (gas dehydration drying)

Therefore, the following items were determined as the measurement items for drying evaluation in the drying process experiment.

- Temperature of the mock fuel rod, heater rod, and gas
- Pressure within chamber
- Flow rate at outlet and after remove the moisture

The following items will be included within the budget allowed.

- Gas composition after moisture removal
- Special glass window for preventing the distortion of wave and observation of the ice formation

3. Measurement System

According to the regulatory guidelines and standards for dry storage of spent nuclear fuel, it is estimated that the drying is sufficiently performed when the internal pressure is maintained within 3 torr for 30 minutes in case of the vacuum drying method [1], and when the cold trap temperature is maintained below -7°C for 30 minutes in case of the gas dehydration drying method [2]. We can perform a dryness evaluation as well as calculate the amount of the residual moisture in the canister of the dry storage system, if we could be known the pressure in the canister of the dry storage system and the temperature in the cold trap of the drying system when drying the canister of the storage system using drying equipment. Therefore, pressure and temperature measurements are required.

The regulatory guidelines and standards for dry storage of spent nuclear fuel specify that the integrity of spent nuclear fuel must be maintained during the drying process. Therefore, it is necessary to evaluate whether the temperature of the simulated fuel rod is maintained within allowable temperature.

While the temperature or pressure is deeply relate to the state or quality of the drying process, the flow rate mainly determines the balance of the process material relative to the amount of water in the drying process. Therefore, it is necessary to measure the mass flow rate in the drying process and the dehydration efficiency of the dehydrator or the condenser by measuring the mass flow rate of the gas from the outlet of the test chamber and the dehydrator.

Accordingly, the main items and measurement positions that need to be measured for the dryness evaluation in drying experiment of the spent fuel dry storage system were determined as follows;

- Pressure in the test chamber
- Temperature in dehydrator of drying system
- Mass flow rate at outlet of test chamber
- Mass flow rate through dehydrator or condenser
- Moisture content of the gas passing through the dehydrator or condenser
- Analysis of the composition of the gas passing through the dehydrator or condenser (provided that the budget permits)

The measurement system capable of measuring pressure and flow rate will be added in the temperature measurement system that is currently owned by the Korea Atomic Energy Research Institute. In addition, a moisture analyzer capable of directly measuring the moisture content of the gas passing through the dehydrator or condenser was selected and the purchase was completed.

We plan to install an emission capable of analyzing the composition of the gas under the condition that the budget allows. Fig. 2 shows the configuration of the measurement system

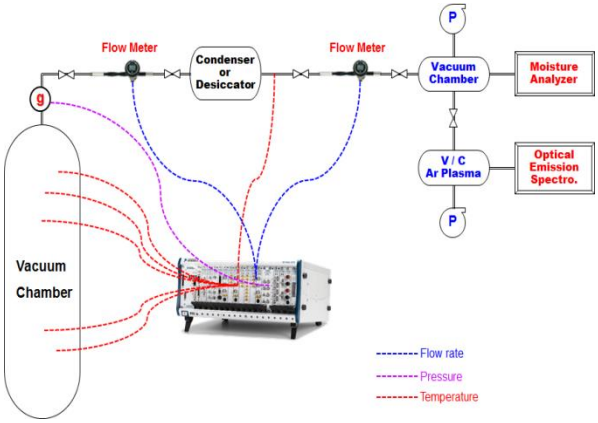

Fig. 2. Configuration of Measurement System.

ACKNOWLEDGEMENTS

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REFERRENCES

[1] NUREG-1536, Rev. 1, "Standard Review Plan for Spent Fuel Dry Cask Storage Systems", U.S. NRC Washington, DC, July 2010.

[2] Dry Storage Handbook, 2015 Edition "Fuel Performance in Dry Storage", ANT International, Molnlycke, Sweden, 2015.