Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Comparison of Vacuum and Forced Helium Drying Methods for Dry Storage of Spent Nuclear Fuel

Ju-Chan Lee*, K.S. Bang, S.H. Yu, K.S. Seo, W.S. Choi
KAERI, 111, Daedeok-daero 989Beon-gil, Yuseong-gu, Daejeon, Korea
**Corresponding author: sjclee@kaeri.re.kr*

1. Introduction

The transport or storage cask of spent nuclear fuel contains an empty canister is placed in a spent fuel pool for loading fuel assemblies. After the loading of the spent fuels in the canister, the cask is moved to the cask-preparation area from the spent fuel pool. The bulk water is then drained from the canister, and residual moisture is removed through a drying process. Finally, helium gas is filled in the canister for the dry storage of the spent fuels.

The purpose of drying and filling helium gas in the canister is to prevent corrosion and hydration of the spent nuclear fuels as well as corrosion of internal canister components during the dry transport and storage. The drying process takes a considerable amount of time to be completed. Therefore, it is a key activity in the spent fuel loading process. There are two types of drying methods: vacuum and forced helium drying. The vacuum drying process depends on reduced pressure to evaporate moisture from the canister, whereas in the forced helium drying process, the moisture is removed by blowing down the canister by using helium gas.

In this study, these two types of drying processes were compared and analyzed to obtain the basic design data for a drying system of a spent fuel canister.

2. Vacuum Drying System

The vacuum drying process is simple and effective in removing residual water from the canister. A vacuum drying system consists of vacuum pumps, vacuum pipe lines, valves, pressure gauge, a particle filter, and a cold trap. This system is connected to the canister port, and the pressure in the canister is reduced to evaporate and remove residual moisture. Several cycles of evacuation and refill are accomplished until the acceptance criteria of pressure and holding time are fulfilled.

Fig. 1 shows the flow diagram of a vacuum drying process. After spent fuel loading, a canister lid is installed on the canister body. Next, a vacuum drying system is connected to a canister to remove water from the canister. The internal pressure is then reduced gradually to prevent the formation of ice in the canister. The acceptance criteria for vacuum drying is a pressure of less than or equal to 4.0 E–04 MPa (3 torr) during 30 min [1]. Therefore, the drying process should be continued until the pressure of the canister stabilizes for 30 min at 3 torr or less.

The internal volume of the KORAD-21 [2] spent fuel canister is 6.46 m^3, excluding the volume of spent fuels and internal structures. If the internal pressure of the canister is 3 torr, the amount of residual water in the canister is determined through the Ideal Gas Law.

$$PV = nRT$$

$$\frac{P_1V_1}{n_1} = \frac{P_2V_2}{n_2} = RT$$

$$n_2 = \frac{P_2V_2}{P_1V_1} n_1$$

$$n_2 = \frac{3torr \times 6.46m^3}{760torr \times 22.4\ell} \times 1mole = 1.138mole(20.5g)$$

The maximum amount of residual water is calculated as 20.5 g during the vacuum drying process of the KORAD-21 cask. Therefore, if we can measure the internal canister pressure under the vacuum drying process, we can estimate the amount of residual water in the canister.

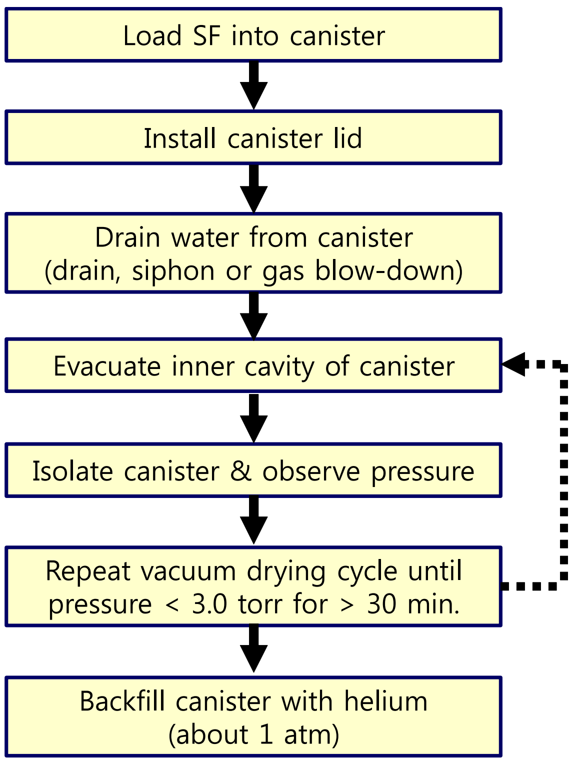

Fig. 1. Flow diagram of vacuum drying process

3. Forced Helium Drying System

In a forced helium drying system, dry helium is circulated through the canister to evaporate and remove moisture.

Fig. 2 shows the flow diagram of the forced helium drying process. The system consists of a condenser module, demoisturizer module, helium circulator module, and preheater module. The condenser module cools down the humid helium discharged from the canister to a temperature below its dew point to extract water from the helium. The demoisturizer then receives partially cooled helium discharged from the condenser module and continuously cools down the recirculating helium to a low temperature corresponding to the partial pressure of water vapor at 3 torr. In addition, the preheater module preheats the circulating helium to the desired temperature such that it is sufficiently warm to absorb the residual moisture in the canister.

Fig. 3 shows the pressure–temperature cycle for the forced helium drying process. For the canister vent port, the humid helium passes through to the condenser and cold trap, where water is extracted along path C–D–A. The cold trap temperature should be lower than −6 °C at 1 atm for its vapor pressure to be less than 3 torr. Gas circulation and moisture removal continues until the vapor pressure achieves less than 3 torr along path A–B–C–D_{final}. The helium gas is heated using a preheater along path A–B, and then passed through the canister. Dry helium is recirculated through the canister until the dew-point temperature of helium achieves the acceptance criteria. The moisture concentration of the helium increases in the canister along path B–$C_{initial}$.

The canister is considered to be dry when the helium temperature discharged from the demoisturizer is less than −6 °C such that the partial pressure of the water vapor in the canister is less than 3 torr [3]. Therefore, the amount of residual water can be determined by the measurement of helium temperature at the demoisturizer. If helium temperature at the demoisturizer is measured as −6 °C, the saturated water-vapor pressure is 3 torr and water vapor is 3 g/m^3 at this temperature. Therefore, the amount of residual water is calculated as 19.4 g (1.1 mole) for the KORAD-21 cask.

The forced helium drying system consists of complicated equipment, including helium circulator, external heating, and cooling units, and has some advantages over the vacuum drying system. The forced helium drying system eliminates the possibility of ice formation in the canister, and the spent fuels are maintained at lower temperatures by forced convective heat transfer. In addition, the drying time can be reduced than that in the vacuum drying system. Therefore, the exposure to occupational workers could be reduced because of the shorter drying times.

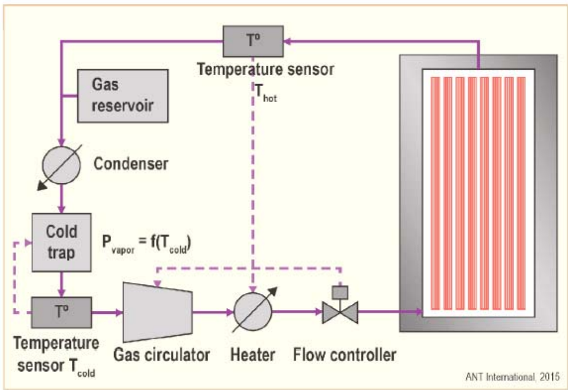

Fig. 2. Flow diagram of forced helium drying process

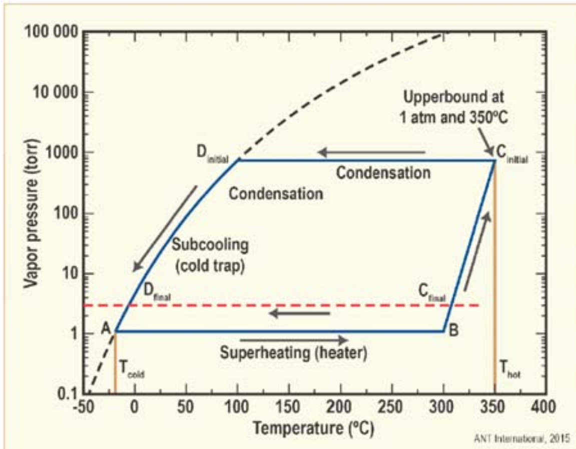

Fig. 3. Pressure–temperature cycle of helium drying process

4. Conclusions

In study, two types of drying process technologies were compared and analyzed. The forced helium drying system is more complicated than the vacuum drying system. However, the helium drying system has some advantages. The main advantage is the heat transfer efficiency in the canister. Another advantage is the shorter drying time relative to vacuum drying. Moreover, the amounts of residual water in the canister during the drying processes were estimated through theoretical analysis. The results of this study will be used as the basic design data in a helium drying system.

REFERENCES

[1] ASTM C-1553-16, "Standard Guide for Drying Behavior of Spent Nuclear Fuel, ASTM, 2016.

[2] Topical Report for Concrete Storage Cask (Rev.2), KORAD, 2014.

[3] Storage, Transport, and Repository Cask System (HI-STAR Cask System) Safety Analysis Report 10 CFR 71 DOCKET 71-9261, Holtec Int'l, 2006.