Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 27-28, 2016

Effect of Operating Pressure on Hydrogen Risk in Filtered Containment Venting System

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1. Introduction

The FCVS (Filtered Containment Venting System) has the main objectives of both the depressurization in the containment building and the decontamination of fission products generated under a severe accident. One of the commercial wet-type FCVSs consists of a cylindrical pressure vessel including a scrubbing solution and filters. A FCVS vessel can be installed on the outside of the containment building, and is connected with the containment through a pipe. When the pressure in the containment building approaches the setting value, a valve on a pipe between the containment and the FCVS opens to operate the FCVS. The amount of steam and gas mixtures generated under a severe accident can be released into the FCVS, where the nozzles of a pipe are submerged into a scrubbing solution in a FCVS vessel. Non-condensable gases and fine aerosols can enter a scrubbing solution, and they then pass the filters. The decontaminated gases are finally discharged from the FCVS into the outside environment. Previous studies have introduced critical issues with the operation of the FCVS [1]. They showed that a hydrogen combustion can occur during the early operation of the FCVS, and the decontamination factor of metal iodide aerosols, particularly CsI (cesium iodide), on a scrubbing solution in the FCVS during a long operation was reduced by the evaporation of a solution. This paper summarized the previous study submitted to the NUTHOS-11 [2], which calculated the mole fraction of steam, air, and hydrogen in the containment and a FCVS vessel.

2. Methods and Results

2.1 Modeling of FCVS in MELCOR code

The MELCOR computer code (v. 1.8.6) simulated that one of the severe accident scenarios, an SBO (Station Blackout), occurred in a target nuclear power plant, an OPR (Optimized Power Reactor) 1000. The reactor type is a PWR (Pressurized Water Reactor) with a thermal power of 2,815 MWt. It is assumed that the FCVS operates when the pressure in the containment building reaches 5 bar. A cylindrical vessel for the FCVS has a 3 m diameter and 6.5 m height, and includes a scrubbing solution of 21 tons, i.e., the pool depth is 3 m, as shown in Fig. 1. The inlet of the FCVS vessel is connected with the containment dome through a venting pipe with a 0.25 m diameter. The exit of a venting pipe is submerged into a scrubbing solution in a FCVS vessel, and is located 2 m below the surface of a pool. A venting pipe includes a multi-hole sparger. The outlet of a FCVS vessel is linked to the outside environment through an exhaust pipe with a 0.25 m diameter. During the operation of the FCVS, we can calculate the thermal-hydraulic condition in a FCVS vessel using the MELCOR code.

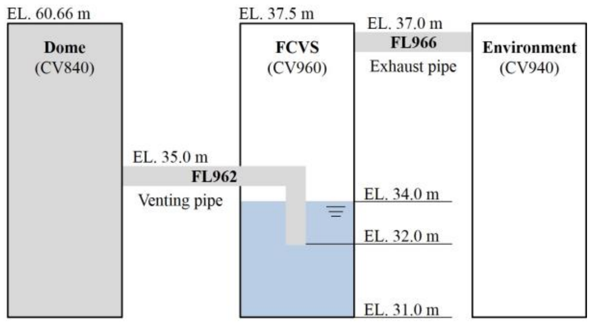

Fig. 1. Modeling of the FCVS [1].

2.2 Hydrogen Issue in FCVS

The pressure and temperature in the containment building increased continuously after the start of a severe accident, because of an amount of steam and gases generated by the chemical reaction between the high-temperature molten core material and coolant or structures. The pressure in the containment building decreased as soon as the pressure approached 500 kPa as a set value of the operation of the FCVS. The pressure in a FCVS vessel jumped suddenly at about 44 hours when the pressure in the containment building approached 500 kPa, because steam and gases created in the containment building under a severe accident are discharged into a FCVS vessel. After the pressure approached the peak value, it decreased in time, because the decontaminated materials passed through scrubbing solution, and the filters in a FCVS vessel are discharged continuously out of the FCVS. The gas temperature also jumped by 395 K because of high-temperature steam and gases injected into a FCVS vessel. The hydrogen concentration in the mixture of steam and gases injected into a FCVS vessel can be changed by large variations of thermal-hydraulic conditions between before and after the operation of the FCVS.

The volume concentrations of steam, hydrogen, and air in the containment building were calculated as 58%, 6%, and 27%, respectively. A mixture of steam and gases with the volume concentrations mentioned above was released into a FCVS vessel under a large difference in the thermal-hydraulic conditions compared with the containment building. At 157,100 s, i.e., as soon as the operation of the FCVS, the volume concentrations of steam, hydrogen, and air in a FCVS vessel were calculated as 2%, 14%, and 61%, respectively. The volumetric concentration of hydrogen increased from 6% in the containment to 14% in the FCVS vessel, while the concentration of steam decreased, because the steam condensation can occur at a relatively low temperature of scrubbing solution in a FCVS vessel. The increased volumetric concentration of hydrogen accompanying the other concentrations of steam and air in the atmosphere of a FCVS vessel can exist within the region of the burn limit in the Shapiro diagram, which indicates the sustainability of the hydrogen combustion. It is expected that the possibility of a hydrogen combustion, which produces the thermal and dynamic load, can threaten the integrity of a FCVS vessel.

2.3 Effect of Operating Pressure on Hydrogen Risk

A hydrogen risk, as mentioned in chapter 2.2, can be mitigated by controlling the amount of steam condensation in a FCVS vessel because the volume concentration of steam mixed with a combustible gas can affect the possibility of hydrogen combustion. It is expected that the steam contents released into a FCVS vessel reduces when the operating pressure of the FCVS decreases. Reference [2] calculated the variation of gas mixture compositions at the operating pressure of 2 bar, and compared with that at 5 bar, where the other conditions used to calculate an accident progress were the same with the exception of the operating pressure of the FCVS.

Table 1 shows the mole fractions of steam, air, and hydrogen in the containment right before the operation of the FCVS. The mole fraction of steam at 2 bar is 46% smaller than that at 5 bar, while the hydrogen concentrations are similar at both 2 and 5 bar. The steam content of a gas mixture discharged into a FCVS vessel decreased owing to the lower operating pressure of the FCVS.

Table 1. Mole fractions of steam, air, and hydrogen in the containment [2]

	Steam	Air	Hydrogen
2 bar	0.311	0.595	0.062
5 bar	0.582	0.262	0.060

Table 2 shows the mole fraction of steam, air, and hydrogen in a FCVS vessel right after the operation of the FCVS. For both of the operating pressures of 2 and 5 bar, steam released into the FCVS vessel was condensed and the hydrogen concentration was relatively increased. In a comparison of Table 1 and 2, the mole fraction of hydrogen in a FCVS vessel increased by 40% at the operating pressure of 2 bar, whereas it increased by 131% at 5 bar. The mole fraction of steam decreased by 89% and 96% at 2 and 5 bar, respectively.

Table 2. Mole fractions of steam, air, and hydrogen in a FCVS vessel [2]

	Steam	Air	Hydrogen
2 bar	0.033	0.834	0.087
5 bar	0.021	0.616	0.139

3. Conclusions

Reference [2] assessed the effect of the operating pressure of the FCVS on the hydrogen risk in a FCVS vessel. The volumetric concentrations of hydrogen and steam in a postulated FCVS with a 3 m diameter and 6.5 m height were calculated using the MELCOR computer code (v. 1.8.6). After the operation of the FCVS, the pressure and temperature in the FCVS vessel jumped from the initial conditions of the atmosphere pressure and room temperature. For the FCVS operating pressure of 5 bar, the hydrogen concentration increased from 6% in the containment to 14% in a FCVS vessel, whereas the steam concentration decreased from 58% in the containment to 3% in a FCVS vessel. The increased hydrogen concentration with air in a FCVS vessel can exists within the region of the burn limit in the Shapiro diagram. This possibility of the hydrogen combustion can threaten the integrity of the FCVS. To mitigate the hydrogen risk, the operating pressure of the FCVS was reduced by 2 bar from 5 bar. The mole fraction of hydrogen in a FCVS vessel increased by 40% at an operating pressure of 2 bar, whereas it increased by 131% at 5 bar. The mole fraction of steam decreased by 89% and 96% at 2 and 5 bar, respectively. The hydrogen risk could be reduced by controlling the operating pressure of the FCVS.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science, ICT, and Future Planning) (No. NRF-2012M2A8A4025893).

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