Hydrogen risk in the Containment Filtered Venting System

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1. Introduction

It was observed that the thermal hydraulic conditions in the CFVS (Containment Filtered Venting System) vessel sharply changed markedly [1], especially the steam condensation in the early CFVS operation can affect the hydrogen behavior such as the combustion. This paper summarizes the calculated results on hydrogen concentration in the CFVS vessel, which was presented at The Ninth Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety (NTHAS9) last year [2].

2. Methods and Results

The thermal hydraulic conditions and hydrogen concentration in the CFVS vessel was calculated by using the MELCOR computer code. To simulate a nuclear power plant under a severe accident, the OPR 1000 with a thermal power of 2,815 MWt under a Station Blackout (SBO) was chosen.

2.1 CFVS modeling

The CFVS vessel was connected with the containment building and the environment through a venting pipe and an exhaust pipe, respectively. In the MELCOR computer code, a Control Volume (CV) described the containment building, the CFVS vessel, and the environment, and the Flow Path (FL) simulated the venting and exhaust pipes, as shown in Fig. 1 [1], where the Elevation (EL) was based on a center line of a hot leg connected with a reactor vessel in the containment building. A cylindrical CFVS vessel 3 m in diameter and 6.5 m height had about 21 tons of water as a scrubbing solution. The venting pipe connected with an inlet of the CFVS vessel included the pool scrubbing model in the Radionuclide (RN) package in the MELCOR computer code, and the exhaust pipe at an outlet had a filter model to simulate decontamination in the CFVS. Both pipes were 250 mm in diameter and 6 m length.

2.2 Thermal hydraulic conditions

Thermal hydraulic conditions such as pressure and temperature in the containment building of OPR-1000 and a CFVS vessel under SBO were calculated by the MELCOR computer code. The pressure and temperature increased continuously after the start of a severe accident, because of an amount of steam and gases generated continuously 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 CFVS, because the generated steam and gases in the containment building were released into the CFVS.

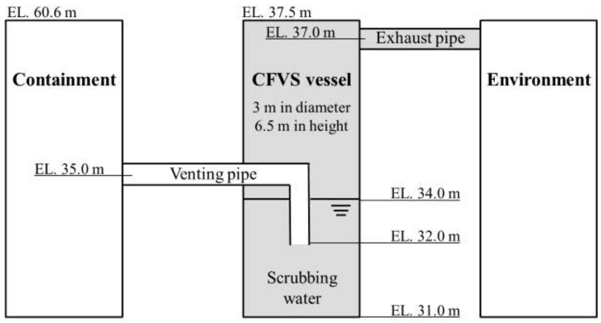

Fig. 1. Modeling of the CFVS vessel [1].

The pressure and temperature in the CFVS vessel are shown in Fig. 2 [2]. The initial conditions of pressure and temperature before the operation of the CFVS were 103 kPa and 305 K, respectively. The pressure in the CFVS vessel jumped suddenly at about 33 hours when pressure in the containment building approached 500 kPa because of the pressure difference between the containment building and the CFVS vessel. Pressure had a peak value of 400 kPa, which is the difference between the final pressure of the containment building of 500 kPa and the initial pressure of the CFVS vessel of 100 kPa. After the pressure approached the peak value, it decreased in time, because the decontaminated materials passed through scrubbing solution and filters in the CFVS vessel are discharged continuously out of the CFVS. The gas temperature also jumped by 395 K because of high-temperature steam and gases injected into the CFVS vessel. After temperature peaks at 33 hours, a relatively low decrement rate of temperature indicates the small difference between the input heat energy into the CFVS and output, i.e., high-temperature steam and gases pass through the CFVS vessel with little heat transfer. Hydrogen concentration in the mixture of steam and gases injected into the CFVS vessel can be changed by the big variations of thermal-hydraulic conditions between before and after the operation of the CFVS.

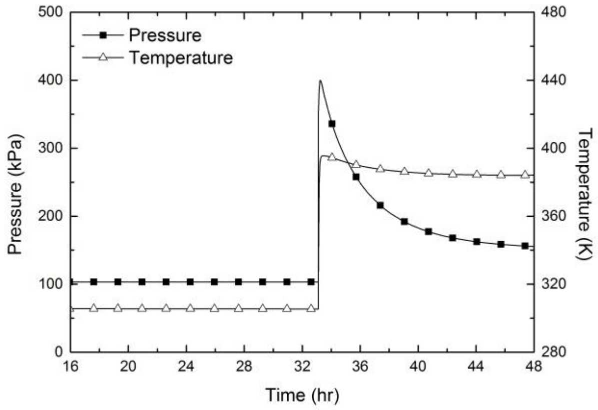

Fig. 2. Pressure and temperature in the CFVS vessel [2].

2.3 Hydrogen concentration

Before the operation of the CFVS, the volume concentrations of steam, hydrogen, and air consisting of oxygen and hydrogen in the containment building were 58%, 6%, and 27%, respectively. A mixture of steam and gases with the volume concentrations mentioned above was released into the CFVS vessel under a large difference in the thermal-hydraulic conditions compared with the containment building.

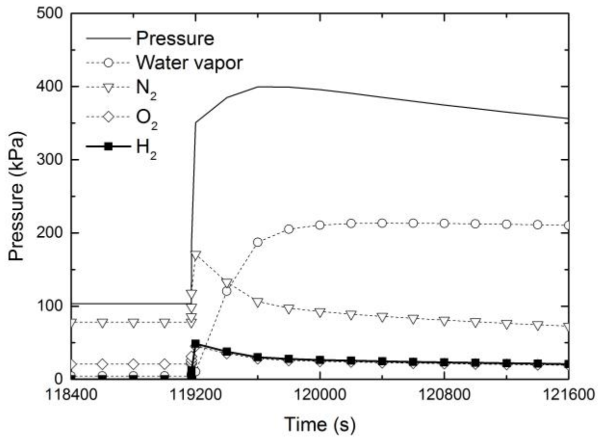

Fig. 3. Partial pressure of gases in the CFVS vessel [2].

The partial pressures of steam and non-condensable gases are shown in Fig. 3 [2], where the pressure in the CFVS vessel is presented as a solid line. The time scale is expanded based on the moment of the operation of the CFVS at 119173 seconds (about 33 hours), where the partial pressure divided by pressure can be converted by the volume concentration, because the summation of partial pressures of steam and gases is the pressure from the Dalton's law. At 119200 seconds, i.e., as soon as the operation of the CFVS, the volume concentrations of steam, hydrogen, and air in the CFVS vessel were calculated as 3%, 14%, and 60%, respectively. The volumetric concentration of hydrogen increased from 6% in the containment to 14% in the CFVS vessel as soon as the CFVS was operated, while the concentration of steam decreased, because the steam condensation can occur at a relatively low temperature of scrubbing solution in the CFVS vessel. The increased volumetric concentration of hydrogen accompanying the other concentrations of steam and air in the atmosphere of the CFVS vessel exists within the region of the burn limit in the Shapiro diagram that indicates the sustainability of hydrogen combustion. After the operation of the CFVS, it is expected that there is a possibility of the hydrogen combustion that can threaten the integrity of the CFVS vessel.

3. Conclusions

The volumetric concentration of hydrogen in the CFVS vessel was evaluated and compared with that in the containment building to estimate the concentration variation that can affect the hydrogen flammability. The MELCOR computer code calculated the thermal-hydraulic conditions in the containment building of OPR 1000, and in the cylindrical CFVS vessel with 3 m in diameter and 6.5 m in height under an SBO. After the operation of the CFVS, the pressure and temperature in the containment building decreased, and those in the CFVS vessel jumped from the initial conditions of atmosphere pressure and room temperature. These big differences of thermal-hydraulic conditions can make the volumetric concentrations of steam and gas mixtures in the CFVS vessel to be changed in comparison with those in the containment building. The volumetric concentration of hydrogen increased from 6% in the containment to 14% in the CFVS vessel after the operation of the CFVS, while the concentration of steam decreased from 58% in the containment to 3% in the CFVS vessel. The increased volumetric concentration of hydrogen (14%) with the other concentrations of steam (3%) and air (60%) in the CFVS vessel exists within the region of the burn limit in the Shapiro diagram. This possibility of the hydrogen combustion can threaten the integrity of the CFVS.

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REFERENCES

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