A Study on Hydrogen Explosion Possibility in the Containment Filtered Venting System During Severe Accident

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1. Introduction

Since the Fukushima accident, the passive safety systems are introduced to cope with Station Black Out (SBO). Among them, the Containment Filtered Venting System (CFVS) filters radioactive materials then vent the gases to the external environment, maintain the pressure of the containment building [1]. The wet-type CFVS consists of inlet and outlet pipes and a vessel. An isolation valve is installed in front of the inlet pipe, to prevent gas leakage in normal operation. A scrubber and scrubbing pool, which decontaminate radioactive materials, is located at the CFVS vessel. A metal fiber filter, which is at the upper side of the CFVS vessel, filters the droplets and aerosols which are not filtered at the scrubbing pool. When the CFVS operates, the atmosphere of the containment building, which consists of flammable gas such as hydrogen and carbon monoxide generated by fuel oxidation and Molten Corium-Concrete Interaction (MCCI), flows into the CFVS vessel.

When the gases pass through the scrubbing pool, the steam condenses and the fraction of flammable gases may increase. In such a situation, resulting in the accumulation of flammable gas inside the CFVS the flammable gas may detonate, threatening the integrity of the CFVS. Therefore, it is essential to estimate the hydrogen risk in the CFVS vessel during CFVS operation.

2. Method of analyses

In this study, MELCOR 1.8.6 was used. The Korean 1000MWe pressurized water reactor, the Optimized Power Reactor 1000 (OPR1000), was used as a reference nuclear power plant.

2.1 Nodalization

The OPR1000 was modeled as two hot-legs, two steam generators, four cold-legs, four Safety Injection Tanks (SITs), a pressurizer, and a reactor. The core initial heat output was set to 2815 MWt. The initial inventory of coolant in the RCS was 210 tons and 50 tons for each SIT. The major parameters of the OPR1000 are listed in Table I [2]. Fig. 1 shows the nodes of the containment building. The containment building was divided into 12 control volumes, and the total free volume was about 77,000 m^3. The Passive Autocatalytic recombiners (PARs), which combine the hydrogen with the oxygen inside the containment building, were considered. The CFVS vessel has a cylindrical structure with a diameter of 3 m and a length of 6.5 m. The level of the scrubbing pool was 3 m to avoid leakage of scrubbing water to the external environment during the operation of the CFVS. The inlet of CFVS was connected to the upper compartment of the containment building [2], and the outlet was connected to the external environment. The diameters of pipes are 0.254 m and the lengths are 6 m.

In this study, two types of accidents, SBO and the Large Break Loss of Coolant Accident (LBLOCA), were analyzed. For conservative consideration, all of the active systems were assumed to be failed in both accidents. The double-ended break of the cool-leg was assumed for LBLOCA scenario.

The opening pressure was set to 0.5 MPa, 0.7 MPa, and 0.9 MPa which are between in the range the containment building design pressure and failure pressure. Two different operation strategies, continuous venting, and cyclic venting were considered in this study. For cyclic venting, the closing pressure was set to 0.5 MPa. The CFVS operation conditions are listed in Table II.

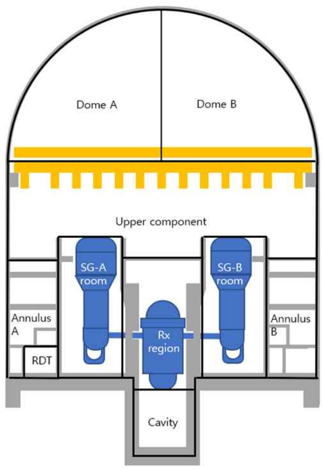

Fig. 1. The containment building nodes

Table I: The major parameters of OPR1000

Parameter	FSAR data
Core thermal output	2815 MWth
RCS pressure	15.82MPa
RCS average temperature	584.7K

Table II: The CFVS operation conditions

Continuous vent	Cyclic vent
Opening at 0.5 MPa	
Opening at 0.7 MPa	Opening at 0.7 MPa and closing at 0.5 MPa
Opening at 0.9 MPa	Opening at 0.9 MPa and closing at 0.5 MPa

2.2 Estimation of the hydrogen risk

The gases like oxygen, nitrogen, steam, carbon monoxide, carbon dioxide, and hydrogen exist in the containment building during a severe accident. These gases can be divided into three groups, that is oxygen, inert gas, and flammable gas. The equivalent values for each group can be evaluated using the following equations :

$$X_{Flammable\ gas} = X_{H2} + 0.5X_{CO} \quad (1)$$

$$X_{Inert\ gas} = X_{H_2O} + X_{CO_2} + X_{N_2} \quad (2)$$

$$X_{Oxygen} = X_{O_2} \quad (3)$$

where ‘X’ represents for mole fraction.

For the hydrogen explosion to occur, the fraction of oxygen and flammable gas should be high, and a fraction of inert gas should be low. The Shapiro diagram can easily show the risk of the hydrogen explosion [4]. The results of Eqs. (1)-(3) were used as the values for the deputy shapiro diagram.

3. Results and Discussions

The changes in gas composition in the CFVS vessel under severe accidents are shown in Figs. 2 and 3. When the CFVS was opened at 0.5MPa or 0.7MPa during the accident scenarios, the flammable gas fraction didn’t exceed 4% and hydrogen risk did not appear in the CFVS vessel. In such the scenario, the MCCI occurred after the CFVS was operated, while the MCCI occurred before the operation of the CFVS when the opening pressure was set as 0.9MPa. In the case of the SBO scenario, MCCI lasted 7 hours before opening, and in LBLOCA scenario, MCCI lasted 4 hours. When the CFVS was opened at 0.9MPa during the accident scenarios, the flammable gas was generated before the initiation of venting. When the venting was started, the flammable gas passed through the scrubbing pool, and the atmosphere in the CFVS vessel entered the burnable zone. The flammable gas fraction reached 12% and 7% in SBO and LBLOCA scenarios, respectively. In Table III, the CFVS opening time and MCCI occurrence time are listed for each accident.

The hydrogen risk was the biggest at 2 minutes right after the initiation of the CFVS operation. The hydrogen risk disappeared after 5 minutes from initiation of the CFVS operation, both in continuous and cyclic venting. which means that the venting method does not affect hydrogen risk in the CFVS vessel.

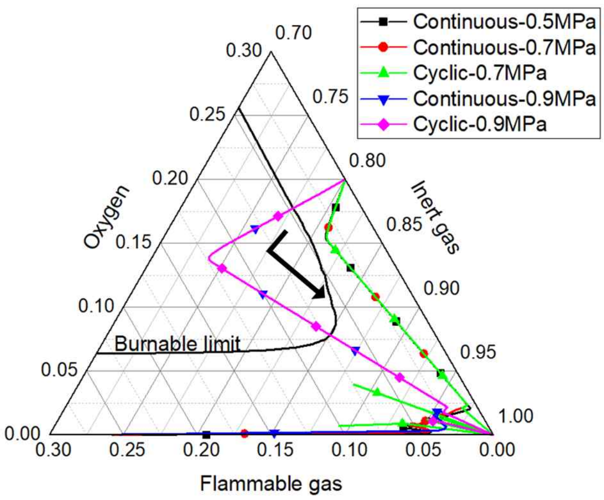

Fig. 2. The Gas composition change in the CFVS vessel under SBO.

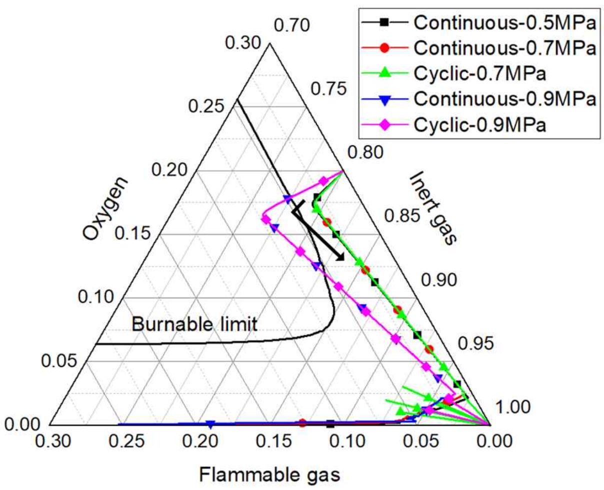

Fig. 3. The gas composition change in the CFVS vessel under LBLOCA.

Table III: The CFVS opening time and MCCI occurrence time under SBO and LBLOCA.

	Time of occurrence [hr]	
	SBO	LBLOCA
CFVS operation when opening pressure set as 0.5MPa	16	12
CFVS operation when opening pressure set as 0.7MPa	24	19
CFVS operation when opening pressure set as 0.9MPa	34	28
MCCI occurrence	27	24

4. Conclusion

In this study, the hydrogen risk inside the CFVS vessel for the different scenarios was evaluated.

When the opening pressure of the CFVS was set as 0.5MPa or 0.7MPa, hydrogen risk did not appear in the CFVS vessel. However, if the opening pressure of the CFVS was set as 0.9MPa, MCCI occurred before the operation of the CFVS, which leads to flammable gas accumulation in the CFVS vessel.
The amount of flammable gas generated until the opening of the CFVS was greater in SBO scenario than that of LBLOCA scenario. Therefore, the hydrogen risk was bigger in the SBO scenario, than the LBLOCA scenario.

The CFVS had the greatest hydrogen risk for about 2 minutes after the initiation of operation. After 5 minutes, the hydrogen risk did not appear in the CFVS vessel, which means the venting method does not affect the hydrogen risk.

From the point of view on the hydrogen risk in the CFVS vessel, the opening pressure of the CFVS should be carefully determined.

Acknowledgments

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