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THERMAL HYDRAULIC ISSUES OF CONTAINMENT FILTERED VENTING SYSTEM FOR A LONG OPERATING TIME

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This study investigated the thermal hydraulic issues in the Containment Filtered Venting System (CFVS) for a long operating time using the MELCOR computer code. The modeling of the CFVS, including the models for pool scrubbing and the filter, was added to the input file for the OPR-1000, and a Station Blackout (SBO) was chosen as an accident scenario. Although depressurization in the containment building as a primary objective of the CFVS was successful, the decontamination feature by scrubbing and filtering in the CFVS for a long operating time could fail by the continuous evaporation of the scrubbing solution. After the operation of the CFVS, the atmosphere temperature in the CFVS became slightly above the water saturation temperature owing to the release of an amount of steam with high temperature from the containment building to the scrubbing solution. Reduced pipe diameters at the inlet and outlet of the CFVS vessel mitigated the evaporation of scrubbing water by controlling the amount of high-temperature steam and the water saturation temperature.

KEYWORDS : Containment Filtered Venting System (CFVS), Severe Accident, Depressurization, Thermal Hydraulic

1. INTRODUCTION

To keep the integrity of the containment building, it is important to mitigate a severe accident involving significant core degradation, where the melted core could react with coolant and structures, thereby causing the continuous generation of steam and gases. Eventually, the containment building would be damaged by overpressure due to the release of abundant steam and gases if the safety systems in the containment building do not work normally.

To depressurize the containment building, the steam and gases could be vented by a Containment Filtered Venting System (CFVS) installed outside of the containment building. Figure 1 shows a conceptual schematic of the CFVS involving scrubbing water and a filter (Ref. 1). When the pressure in the containment building undergoing a severe accident approaches the setting pressure, which should be smaller than the failure pressure of the containment building, an isolation valve on a venting pipe connecting the containment building to the CFVS is opened. Steam and gases flow from the containment building into the CFVS vessel through the venting pipe, and the pressure in the containment building can then be decreased. In addition to depressurization, fission products can be decontaminated by injecting them into the scrubbing solution and by passing them through the filters in the CFVS vessel. Finally, the clean gases could be released from the CFVS vessel into the environment through an exhaust pipe.

Long term operation of the CFVS is necessary for the integrity of the containment building if the safety systems in the containment building have not only failed under a severe accident, but also cannot be restored in a short time. This study carefully examines the possible thermal hydraulic issues that can induce the evaporation of scrubbing water in the CFVS for a long operating time.

2. METHODS

2.1 Input Preparation

The Korean Standard Nuclear Power Plant called the OPR-1000, which is a pressurized water reactor with a thermal power of 2,815 MWt, was selected as a target nuclear power plant in this study.

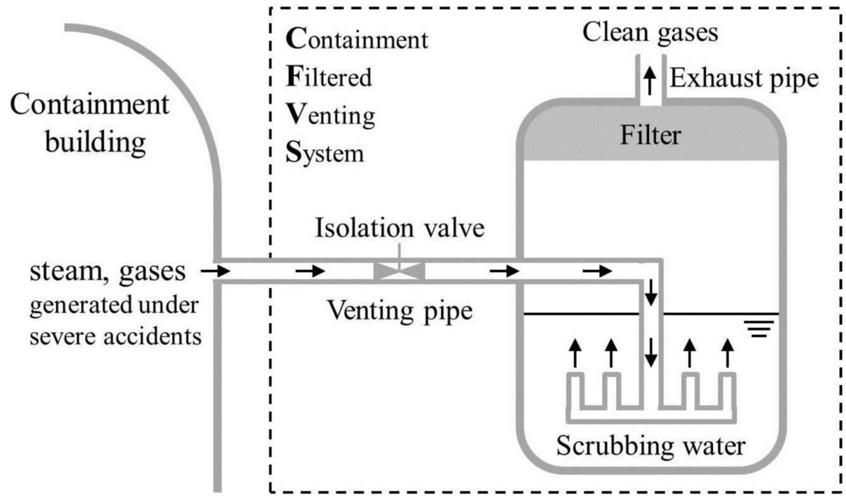

Fig. 1. Conceptual Schematic of the CFVS.

A Station Blackout (SBO) was chosen as the accident scenario where on-site and off-site electrical systems do not work. It is assumed that the emergency core cooling systems such as High Pressure Safety Injection (HPSI) and Low Pressure Safety Injection (LPSI) are not operational during the accident. At the start of the SBO, the reactor and turbine are tripped, the pumps for the Main Feed Water (MFWs) and Auxiliary Feed Water (AFWs) are stopped, and the Main Steam Isolation Valve (MSIV) is closed.

An accident analysis for the OPR-1000 under an SBO was conducted using the MELCOR computer code (Ref. 2), where the input files were modified to make a venting hole for a flow path connecting the containment building with the CFVS (Ref. 3), and the modeling for the CFVS vessel was added (Ref. 4).

2.2 Modeling of the CFVS in the MELCOR Computer Code

To calculate the thermal hydraulic conditions in the CFVS using the MELCOR computer code, a vessel for the CFVS was modeled as a control volume of 3 m in diameter and 6.5 m height, as shown in Fig. 2. This stainless steel vessel, including about 21 tons of scrubbing water, has a convective boundary condition with the heat transfer coefficient given by the MELCOR computer code (Ref. 5). The CFVS was connected with the containment building and the environment through a venting pipe and an exhaust pipe, respectively, as a flow path with 25 cm diameter. Although multiple venting pipes should be considered in a real CFVS to prevent an unexpected blockage in a pipe or trouble with an isolation valve, a single venting pipe was used in this study for computational convenience. The pool scrubbing model and filter model in the MELCOR computer code (Ref. 5) were applied to simulate features of scrubbing water and the filter in the CFVS, as shown in Fig. 1. The pool scrubbing model applied to the venting pipe was based on the SPARC 90 code for calculating the fission product capturing in suppression pools; it contains models to simulate aerosol particle growth, scrubbing, bubble breakup, and capture of vapor iodine species (Refs. 6 and 7), and the pool scrubbing model involves a multi-hole sparger to prevent a water slug. In the filter model for the exhaust pipe, decontamination factors (DF) for aerosol and vapor were set to 10, i.e., 90% of radioactivity can be removed in the filter.

The MELCOR computer code, including the above models, calculated the thermal hydraulic conditions in the CFVS for a long operating time of about 108 hours. When the pressure in the OPR-1000 under an SBO approaches 500 kPa, the setting pressure for operating the CFVS, an amount of steam and gases with high temperature and pressure are released from the containment building to the CFVS vessel through the venting pipe. Fission products are injected into scrubbing water and then fine aerosol and vapor passes through a filter. Finally, it is expected that the pressure in the containment building will decrease, and the decontaminated gases will discharge from the CFVS vessel through an exhaust pipe.

3. RESULTS AND DISCUSSION

3.1 Depressurization in the Containment Building

The pressure in the containment building increased as soon as an SBO occurred, as shown in Fig. 3. When the pressure reached 500 kPa, the CFVS activated, i.e., an

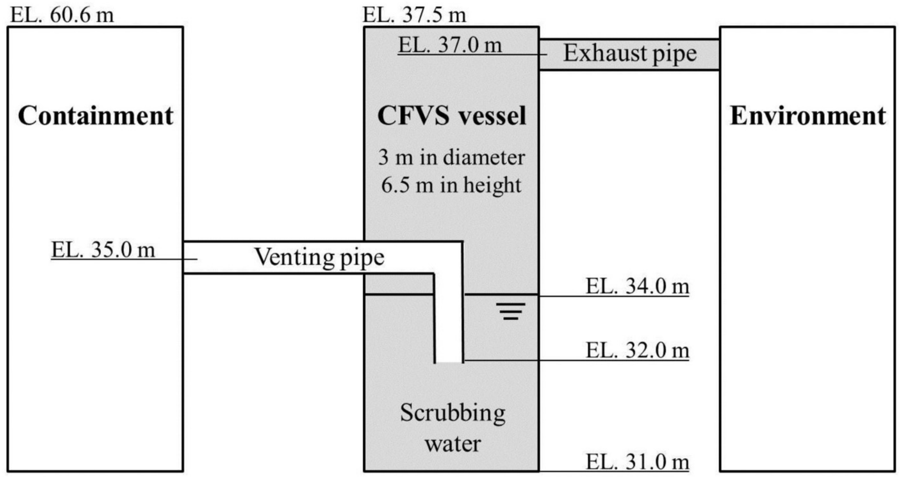

Fig. 2. Modeling of a Vessel for the CFVS.

amount of steam and gases with high temperature and pressure released from the containment to the CFVS, and then the depressurization in the containment building began (Ref. 4). If the steam and gases continuously generated under a severe accident cannot be removed by a safety system, the containment building could fail due to overpressure, indicated as a dashed line in Fig. 3. After operating the CFVS, the pressure dramatically decreased, and then dropped to the initial pressure in the containment building. The pressure variation in the containment building connected to the CFVS under an SBO was explained by the evaporation of a pool and the condensation of steam within the containment building (Ref. 4). There were no pools in the containment building after 51 hrs in Fig. 3, which makes the pressure in the containment building as well as the CFVS vessel decrease quickly. Although the depressurization in the containment building from operating the CFVS seems to be successful, thermal hydraulic issues regarding heat transfer in the CFVS vessel for a long operating time were observed.

3.2 Thermal Hydraulic Conditions in the CFVS

The pressure and temperature in the CFVS vessel were calculated by the MELCOR computer code, as shown in Fig. 4. A solid line indicates the pressure in the CFVS, while the open circles and solid circles represent the atmosphere temperature in the control volume of the CFVS vessel and the water saturation temperature at the pressure of the control volume of the CFVS, respectively. When the CFVS had operated at 33 hours, the pressure in the CFVS peaked due to the release of an amount of steam and gases, and then it decreased in the same manner as the pressure in the containment building in Fig. 3. The initial temperature of the scrubbing water and atmosphere in the CFVS is room temperature. As soon as the CFVS operates, both the water saturation temperature and the atmosphere temperature in the CFVS peaked. The saturation temperature of a pool in the CFVS approached to the atmosphere temperature, which can cause the phase change of a pool from liquid to vapor.

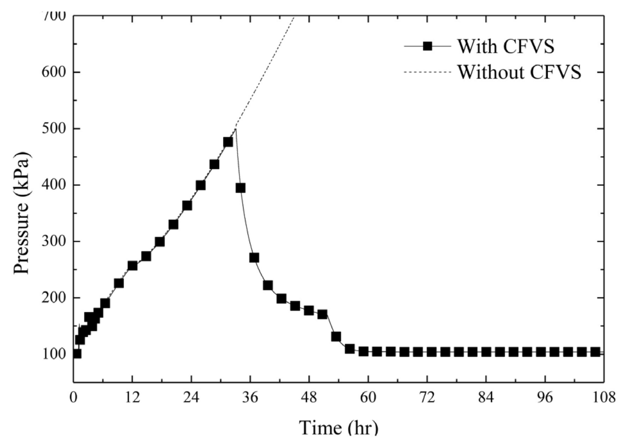

Fig. 3. Pressure Variations in the Containment under an SBO.

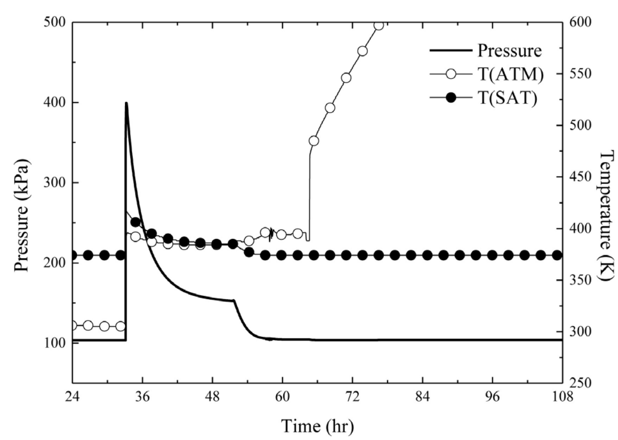

Fig. 4. Thermal Hydraulic Conditions in the CFVS.

The atmosphere temperature in the CFVS increased dramatically at 66 hours under constant pressure. It means that the scrubbing solution in the CFVS fully evaporates, and then becomes superheated steam during the operation of the CFVS.

3.3 Evaporation of Scrubbing Solution

The initial water level of the scrubbing solution in the CFVS was 34 m from the bottom of the vessel, as shown in Fig. 2, and the mass of the pool was 21 tons. As soon as the CFVS operates, the mass of the scrubbing solution in Fig. 5 increased dramatically owing to the condensation of an amount of steam with high temperature released from the containment building. The scrubbing water evaporates continuously after the peak of the mass, and becomes below the initial water level when the atmosphere temperature is slightly above the water saturation temperature. Scrubbing water in the CFVS fully evaporated at 64 hours, and then the atmosphere temperature, indicated as an open circle in Fig. 5, dramatically increased. It seems that the capacity of the CFVS vessel for condensation of injected steam with high temperature is insufficient for a long operating time. Reduced scrubbing solution in the CFVS can adversely affect the decontamination feature for fission products released from the containment building. It is necessary to maintain the initial water level to make a region for the movement of gas bubbles containing the fission products, because heat and mass transfer between the bubble surface and scrubbing solution occur during the rise of bubbles. The breakup and long residence time of the bubbles within the scrubbing water could, therefore, lead to more effective decontamination. In addition, if the scrubbing solution is fully evaporated, an amount of steam and gases with high temperature will directly pass through the filter. Finally, the filters can fail by clogging and corrosion due to an overload of aerosol and high-temperature gases, and the fission products could then be discharged into the environment without decontamination.

3.4 Mitigation of Evaporation

To operate the CFVS with a normal decontamination feature for a long operating time, this study prolongs the evaporation time of the scrubbing water by changing the size of the venting and exhaust pipes in Fig. 2. The amount of high-temperature steam injected into the scrubbing solution decreases with a reduction in the venting pipe size. The peak of the water saturation temperature, corresponding to the pressure in the CFVS, can be maintained by decreasing the exhaust pipe size. The venting and exhaust pipe diameters in Fig. 2 were decreased from 25 cm to 10 cm. Figure 6 shows the effect of the pipe diameter on the water saturation temperature in the CFVS, where the legends are indicated in Table 1.

The decrement rate of water saturation temperature for both 25/10 and 10/25 became slower than that of 25/25. With the operating of the CFVS, the saturation temperature of 25/10, i.e., the case in which the outlet area of the CFVS vessel was reduced, is higher than that of 25/25, because the pressure in the CFVS was maintained higher and longer owing to the increment of the discharge resistance of gases in the CFVS, which showed the same trend with the pressure variation in the CFVS as well as in the containment building (Ref. 4). The peak of 10/25, i.e., the case in which the inlet area of the CFVS was reduced, is lower than that of 25/25, because the amount of high-temperature steam released into the CFVS decreases with a reduction in the venting area.

As we expected above, the evaporation time, as shown in Fig. 7, is maintained longer by the decrement of the pipe diameters. The effect of the exhaust pipe size on the evaporation time is stronger than that of the venting pipe size. With the operating of the CFVS, the increment of mass of the scrubbing solution induced by the steam condensation changes the water level by 1 m from the initial water level of 34 m. Although the evaporation of the scrubbing solution can be mitigated by the decrement of the exhaust pipe size, it adversely affects the depressuri-

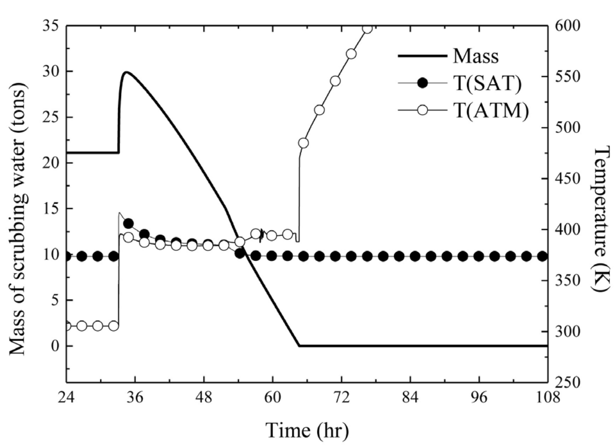

Fig. 5. Evaporation of Scrubbing Solution in the CFVS.

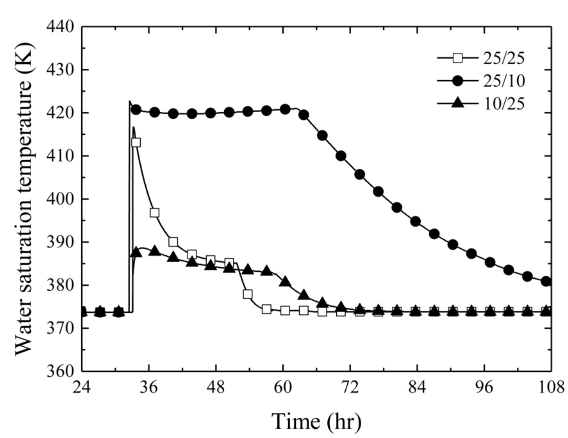

Fig. 6. Effect of Pipe Diameters on Saturation Water Temperature in the CFVS.

Table 1. Pipe diameters in Fig. 6-8

Legends	25/25	25/10	10/25
Venting pipe	25 cm	25 cm	10 cm
Exhaust pipe	25 cm	10 cm	25 cm

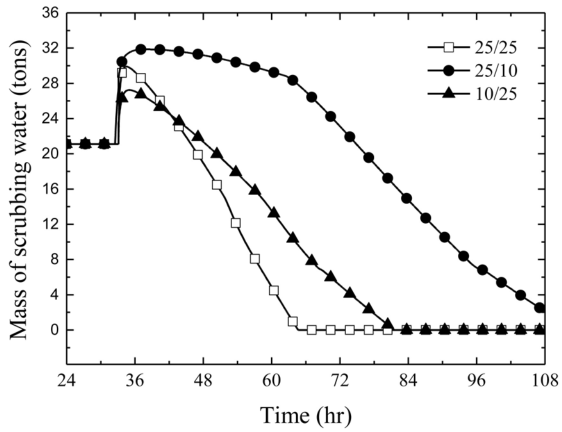

Fig. 7. Delay of Evaporation Time of Scrubbing Solution in the CFVS.

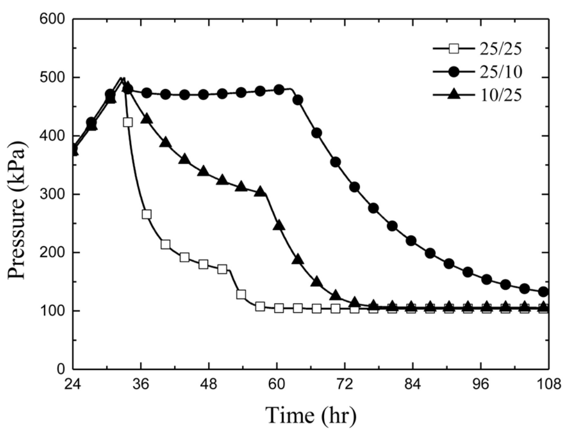

Fig. 8. Effect of Pipe Diameter on Depressurization in the Containment Building.

zation in the containment building as a primary objective of the CFVS. Figure 8 shows the pressure variation in the containment building during the operation of the CFVS. The pressure for the case of 25/10 does not decrease as soon as the CFVS operates at 500 kPa, because the discharge resistance of gases in the CFVS increases with the decrement of the exhaust pipe size. Depressurization in the containment building can fail because of the small area of the exhaust pipe.

4. CONCLUSION

Thermal hydraulic conditions in the Containment Filtered Venting System (CFVS) for a long operating time were investigated using the MELCOR computer code. The modeling of the CFVS, including the models for pool scrubbing and filtering, was added to the input file for a Korean Standard Nuclear Power Plant called the OPR-1000, and a Station Blackout (SBO) was chosen as a severe accident scenario. To simulate a CFVS vessel, a control volume with a 3 m diameter and 6.5 m height was connected with the containment building and the environment through flow paths with a 25 cm diameter. Flow paths connecting with the CFVS were presented as a venting pipe and an exhaust pipe at the inlet and outlet of the CFVS vessel, respectively. The CFVS operates when the pressure in the containment building approaches 500 kPa under an SBO.

The pressure in the containment building was decreased to the initial pressure after operating the CFVS because of the amount of steam and gases generated under a severe accident released from the containment building to the CFVS. Although depressurization in the containment building as a primary objective of the CFVS was successful, the decontamination feature by a scrubbing solution and filter within the CFVS could fail owing to thermal hydraulic issues in the CFVS for a long operating time. After the operation of the CFVS, the atmosphere temperature in the CFVS became slightly above the water saturation temperature because of high temperature steam injected into the scrubbing water, which caused the continuous evaporation of the scrubbing solution. Finally, the scrubbing solution in the CFVS was fully evaporated after 33 hours from the operation of the CFVS. The decrement of water level of the scrubbing solution could adversely affect the decontamination feature of the CFVS. The efficiency of the scrubbing and filtering process could continuously decrease, and the fission products would then be released into the environment without decontamination. To maintain the water level of the scrubbing solution in the CFVS, the evaporation time of the scrubbing solution was prolonged by decreasing the venting and exhaust pipe sizes, i.e., the inlet and outlet areas of the CFVS vessel. The amount of high-temperature steam injecting into the scrubbing solution can be decreased by reducing the venting area, and the water saturation temperature corresponding to the pressure can be maintained longer by reducing the area of the exhaust pipe. The effect of the exhaust pipe size on the evaporation time was stronger than that of venting pipe size. Although the evaporation of the scrubbing solution can be mitigated by the decrement of the exhaust pipe size, the depressurization in the containment building as a primary objective of the CFVS can be adversely affected by the high discharge resistance of gases in the CFVS.

Further studies on the models regarding pool scrubbing and filtering are necessary to precisely simulate the thermal hydraulic conditions in the CFVS for a long operating time. In addition, the sensitivity analysis on various parameters, especially the dimensions of the CFVS containing injection nozzles, should be required to reduce the uncertainty. Thermal hydraulic issues in the CFVS, as well as the containment building, should be considered when designing the CFVS for a long operating time and assessing the performance of both depressurization and decontamination.

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