Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

Numerical Analysis of a Passive Containment Filtered Venting System

Tae-Joon Kim*, Hui-Un Ha, Sun Heo
Advanced Reactor Development Lab., Central Research Institute, Korea Hydro & Nuclear Power Co., Ltd,
70, 1312 Beon-gil, Yuseong-daero, Yuseong-gu, Daejeon, 305-343
**Corresponding author: tj.kim@khnp.co.kr*

1. Introduction

As a part of innovative light-water power plant (called as i-Power) development project, a passive type for Containment Filtered Venting system (CFVS) has been suggested [1]. Most of proven technologies for CFVS are passively operated, but they include manually or electrically driven valves. The passive CFVS does not have principally any kind of isolation valves or filtering devices which need periodic maintenance. In this study, the hydro-thermal analysis is presented to investigate the existence of flow instability [2] in the passive CFVS and its performance under the pressure change of APR+ containment building with LB-LOCA M/E data.

2. Operation Phases and Analysis of Passive CFVS

In this section the four operation phases of Passive CFVS are described. And the results of numerical simulation using GOTHIC8.0 system code follow them.

2.1 Operation Phases

The passive CFVS consists of simple components only of pipes and the Passive Coolant Tank (PCT) as depicted in Fig. 1. In normal operation of the plant, the water is filled throughout the pipe to the height that is same to the level of the PCT. The pipes are divided into three parts for the convenience of consideration: the inner and the outer pipes that are located respectively inside and outside the containment building, and the middle pipe that connects them. The level of water in the inner pipe is determined according to the change of the balance among the pressure of the containment building, hydrostatic pressure inside the pipe and the atmospheric pressure. According to the increase of the containment building pressure, the passive CFVS is considered to operate in four phases as follows.

Phase 1: Pressurization of Containment Building
As the release of steam gas is going on, the pressurized gas in the containment building press down the water level of the inner pipe of the passive CFVS. Because of the relatively huge size of the containment free volume, the local pressure pick or change would not have impact on the level change with respect to the instability of CFVS and the level steadily goes down to the level of the middle pipe to the maximum pressure of the

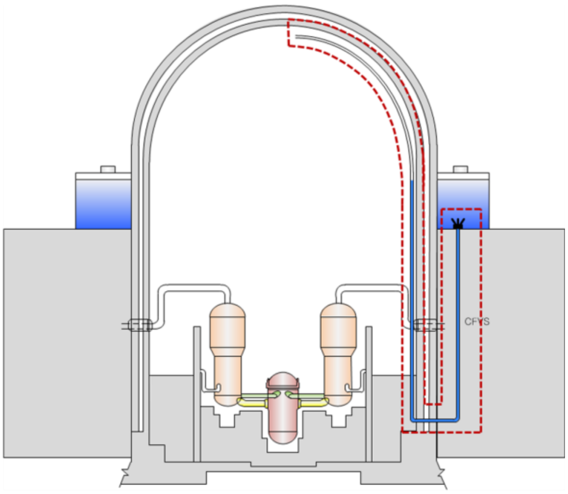

Fig. 1. Conceptual design of the passive Containment Filtered System of i-Power (inside red lines).

containment building, $P_{C.B.\max}$, before gas ejection into the PCT,

$$P_{C.B.\max} = P_{atm} + P_H \qquad 1)$$

where P_{atm} is atmospheric pressure and P_H is the summation of hydrostatic pressures in the outer pipe, P_{H1} and the PCT, P_{H0}.

Phase 2: Loss of Hydrostatic Head
After the containment building pressure reaches $P_{C.B.\max}$, the gas flow begins to vent through the middle pipe. The gas phase flow accelerates upwards inside the outer pipe by gravitation. Then, the hydrostatic head developed due to the liquid stored in the outer pipe abruptly collapse as the pipe is filled with gas bubbles and flow regime changes from bubbly flow to churning flow.

Phase 3: Opening and Gas Ejection
When the hydrostatic head inside the outer pipe is cleared, the gas starts to eject into the PCT in which the particle wastes included in the gas are filtered. If the gas generation rate in the containment building is enough to maintain the gas ejection, the CFVS operation state remains in Phase 3. The containment building pressure, $P_{C.B.}$, changes to the value as

$$P_{C.B.} = P_{atm} + P_{H0} + P_{loss} \qquad 2)$$

where P_{loss} is the pressure loss due to the gas flow inside the CFVS pipe line.

Phase 4: Head Recovery

After the gas in the containment building is exhausted and the containment building pressure decreases to the condition, $P_{C.B.} < P_{C.B.\max}$, the hydrostatic head in the pipe line is recovered by gravitation. During the head recovery, there must be a flow motion like water pendulum inside the CFVS pipe line; however, this is far from unstable flow patterns because the possibility that the containment building pressure would be influenced by the level change of the CFVS line is very low.

In case that the gas generation in the containment building is sustained after the head recovery, the operation phase of the passive CFVS is repeated from Phase 1.

2.2 Numerical Analysis

The containment building was modeled using the specification of APR+ with the volume of 93400 ㎥. The CFVS pipe line has the diameter, 0.5m. The lengths of the inner, middle, and outer pipes are respectively 30m, 2m, 30m. The inner and outer pipes are modeled vertical and the middle pipe horizontal. The simulation was carried out using GOTHIC8.0 system code. The control volume and flow paths used in modeling are depicted in Fig. 2. The cross sections of the pipe control volumes are divided to four subvolumes to describe the local effect of water level change. The calculation was done with three conditions: 1) steam generation inside the containment building of 1kg/s and 0.1kg/s, 2) pressure loss given at the flow paths between the pipe lines, 3) APR+ LBLOCA M/E data condition.

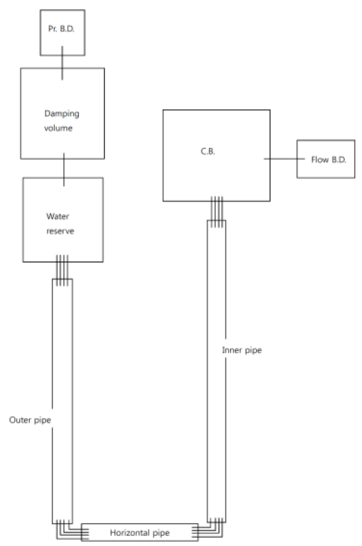

Fig. 2. Control volumes and flow paths used to model the passive CFVS using GOTHIC8.0 .

1) Steam generation inside the containment building

Steam flow rate to the containment building was 400kg/s at first from 0 sec to 295sec to make the pressurization condition in the containment building. From 295sec, two different cases for steam flow rate, 1kg/s and 0.1kg/s have the pressure and water level change as depicted in Fig. 3. The conspicuous difference between the two cases is the existence of Phase 4, i.e. the head recovery. With 1.0kg/s of steam generation, the gas ejection to the PCT continues and the water level of the PCT is increasing slightly, but in case of 0.1kg/s steam rate, the head recovery occurs and water level change also stops. All the pressure of containment building of two cases are maintained to be around the value of the maximum containment building pressure, $P_{C.B.\max}$.

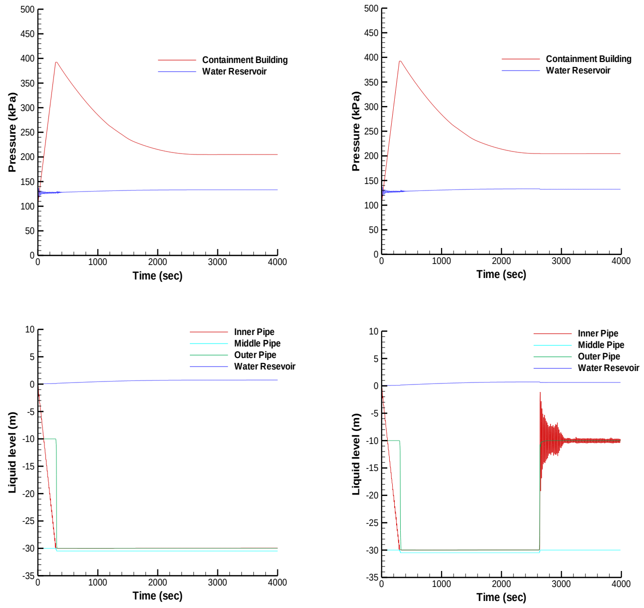

Fig. 3. Containment pressure (upper) and water level changes (lower) of the passive CFVS in the condition of constant steam generation rates in the containment building(left: 1.0kg/s, right: 0.1kg/s).

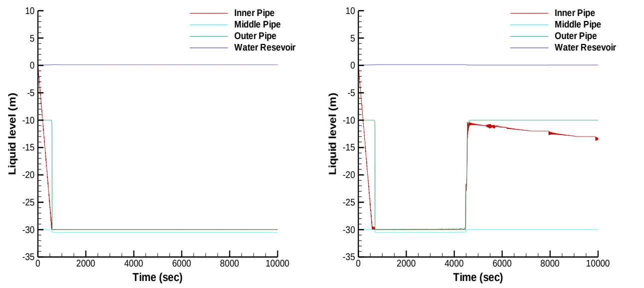

Fig. 4. Water level changes of the passive CFVS compared to see the effect of pressure loss at the pipe connections (left: $\Delta P = 0$, right: $\Delta P \neq 0$).

2) Pressure loss effect on Phase control

The pressure loss can be endowed to the CFVS pipe line simply by changing the flow path condition at the connection of pipes. Then, the pressure loss effect on the development of the passive CFVS operation phases can be seen in Fig. 4. The water level change shows that with $\Delta P = 0$ at the pipe connection, the gas ejection continues at Phase 3, but pressure loss at the connection cause the passive CFVS to have Phase 4, and the pressurization stage (Phase 1) is repeated. This means the possibility of controlling the passive CFVS operation phases to optimize the procedure in dealing with the containment building pressurization.

3) Application to APR+ LBLOCA M/E data input condition

The simulation model was applied to the input condition of APR+ LBLOCA M/E data which was obtained from the results of RELAP5.0 DBA analysis. The gas generation condition is given in Fig. 5. Although the transient flow rate is stabilized into the steady flow rate at 5000sec, the steam flow from RCS is above 0.5kg/s which keeps the gas ejection to the PCT at Phase 3 as seen in Fig. 6. The containment pressure is kept around 2bar during gas ejection.

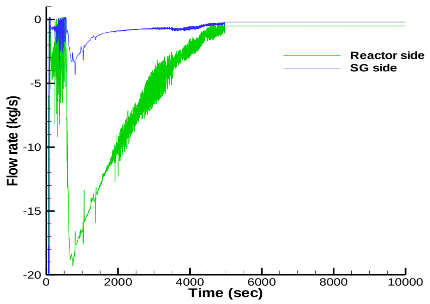

Fig. 5. APR+ LBLOCA M/E steam flow rate input data from RELAP analysis.

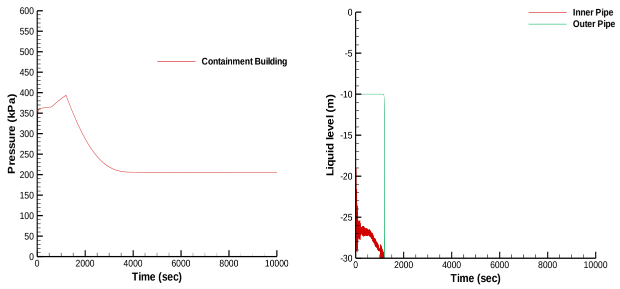

Fig. 6. Containment pressure and water level of the passive CFVS with the input of APR+ LBLOCA M/E data.

3. Conclusions

The Passive Containment Filtered Venting System was suggested as a part in i-Power development project and the operation mechanism was investigated by numerical modeling and simulation using GOTHIC8.0 system code. There are four Phases for consideration to investigate the pressurization of the containment building, loss of hydrostatic head in the pipe line of CFVS, opening of pipe line and gas ejection to the coolant tank, and the head recovery inside the pipe as the containment gas exhausted. The simulation results show that gas generation rate determine the timing of head recovery in the CFVS pipe line and that the equipment of various devices inducing pressure loss at the pipe can give the capacity of Phase control of the passive CFVS operation. APR+ LBLOCA M/E data was applied to the simulation model and the pressure change of the containment showed the performance of the passive CFVS.

REFERENCES

[1] Hui-Un Ha, Sun Heo, Han-Gon Kim, "Containment Filtered Venting System with passive coolant tank of Passive Containment Cooling System", Pat. Application:10-2012-0128856, 2012.

[2] Nikolay Ivanov Kolev, "Flow Boiling and Condensation Stability Analysis", Springer Berlin Heidelberg, pp.195-213, 2012.