Analytical Simulation of the Pipe Rupture Accident of the Heavy Water System in the Reactor Pool

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1. Introduction

In many research reactors, heavy water is used as a moderator and generally contained in the vessel to separate from light water in the reactor pool. It is important to detect the pipe rupture accident of the heavy water system in the reactor pool. In the present study, in order to find out the changes of the system parameters of heavy water system from the normal operation to the abnormal operation, analytical simulation is performed. At here, abnormal operation is defined as a system operation after the inlet or outlet pipe rupture of the heavy water vessel in the reactor pool.

2. Heavy water system and operations

Heavy water system is designed as a closed loop system and consists of pump, head tank, control devices and other equipments as shown in Fig. 1.

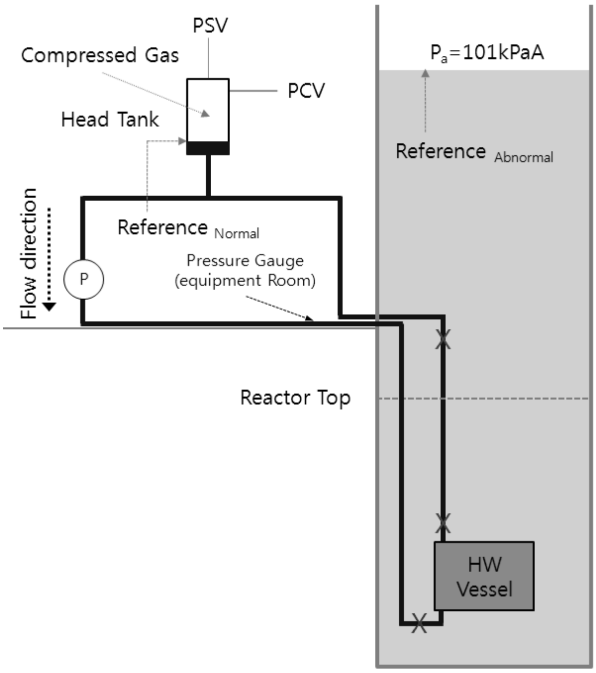

Fig. 1. Schematic diagram of the heavy water system

2.1 Normal operation and abnormal operation

In the normal operation, pump inlet pressure of the closed loop is determined by the heavy water level and static pressure of compressed gas in the head tank. But, when the inlet or outlet pipe of the heavy water vessel is wholly broken, heavy water system is changed from the closed loop to the open loop. Consequently, reference pressure of the system is shifted from the inside of the head tank to the surface of the reactor pool as shown in Fig. 1. At here, the pool surface is exposed to the atmosphere. Anticipated locations of the pipe rupture in the reactor pool are represented in Fig. 1. In abnormal operation, it is difficult to find out the accident state by using the existed instruments like system flow rate and temperature alarms. It would be judged as the normal operation apparently.

2.2 Hydraulic static pressure distribution

Inside heavy water and outside light water at the vessel top are the same hydraulic static pressure by means of the general arrangement and compressed gas pressure in the head tank as shown in Fig. 2. Hydraulic static pressure of the heavy water is slightly higher than that of the light water with pool depth due to the density difference.

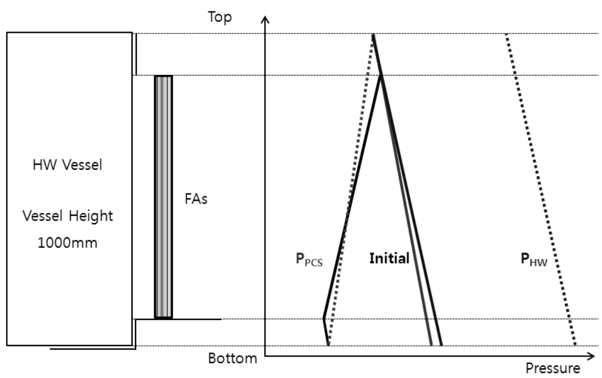

Fig. 2. Hydraulic static pressure distribution of the heavy water and light water inside and outside the HW vessel

2.3 System parameters

The rupture of the pipe in the reactor pool and ensuing changes of the system parameters are simulated analytically. There are three kinds of system parameters chosen in the present study to detect the transition of the heavy water system: heavy water level in the head tank, pressure at the inlet pipe of the heavy water vessel located in the equipment room and input power of the circulation pump. The position of the pressure gauge is depicted in Fig. 1. Following section describes the above system parameters in detail.

2.4 Heavy water level in the head tank

In the abnormal operation, static pressure at the point 'A', the junction of the branch pipe connected to the head tank and the main system pipe as shown in Fig. 3, is changed due to the shift of reference pressure. The static pressure at this point is calculated as described in Equation (1).

$$P = P_0 - P_{sys} - \rho g H - \frac{1}{2}\rho V^2 \qquad (1)$$

P_0 : Total pressure at the pipe rupture location

P_{sys} : Pressure loss in the HW system

H : Depth from the point 'A' to the pipe rupture location

Then, water level in the head tank is determined based on this static pressure. At here, water level is affected by the liquid density. But this effect is less important than the system pressure loss. The change of the water level is represented in Fig. 3.

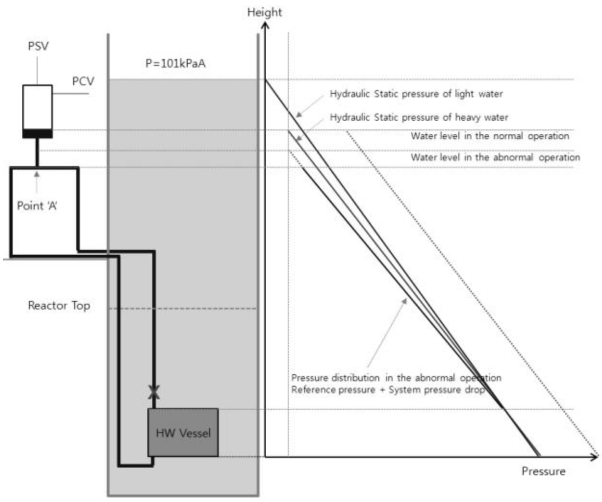

Fig. 3. Analytical simulation of the abnormal operation

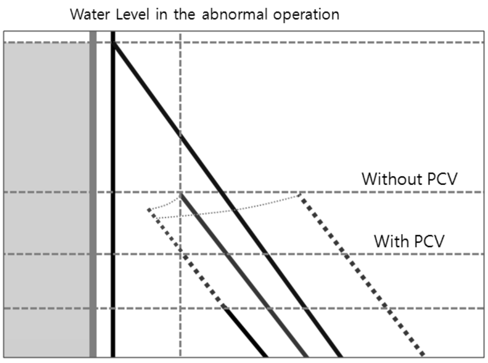

Fig. 4. Analytical simulation of water level in the head tank without PCV in the abnormal operation

In this simulation result, PCV(Pressure Control valve) connected to the head tank plays a important role to determine the water level in the abnormal operation. If there is no PCV on the head tank, the water level change is smaller than the above result duo to the gas expansion and then pressure decrease as explained in Equation (2) and Fig. 4.

$$PV = nRT \qquad (2)$$

2.5 System pressure distributions

Pressure distributions of the heavy water system are changed in the abnormal operation as mentioned above. Pressure at the inlet pipe of the heavy water vessel becomes lower in the abnormal operation because of the shift of the location of the reference pressure and pressure loss.

2.6 Pump input power

Operating point of the circulation pump is not shifted and flow rate of the heavy water system is maintained in the abnormal operation. But, input power of the pump is decreased by 10% because the working fluid is gradually changed from heavy water to light water.

3. Conclusions

Three kinds of system parameters are selected and simulated analytically to find out the pipe rupture accident of the heavy water system in the reactor pool water. System parameters and its transitions are summarized below.

(1) Water level in the head tank : Decrease
(2) Pressure at the inlet pipe of the HW vessel : Decrease
(3) Input power of the circulation pump : Decrease

REFERENCES

[1] S. L. Dixon, Fluid Mechanics, Thermodynamics of Turbomachinery, Fifth Edition, Elsevier, London, 2005
[2] B. R. Munson, D. F. Young, T. H. Okiishi, Foundamentals of Fluid Mechanics, Fourth Edition, John Wiley & Sons, 2002.
[3] R. L. Mott, Applied Fluid Mechanics, Fifth Edition, Prentice Hall, 2000.