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Hydraulic characteristic of two-phase natural circulation loop as PCCS and visualization

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1. Introduction

Passive Containment Cooling System (PCCS) is essentially considered at advanced nuclear power plant such as AP1000, HPR1000, etc. to keep the integrity of containment building on severe accident [1,2]. However, unlike advanced nuclear power plant which considered the only condensation at the outside of heat exchanger under design process, operated nuclear power plant have to consider both condensation and boiling at the outside and inside of the heat exchanger, respectively, because of its limited space for constructing the PCCS. Despite, the mechanism of the PCCS is very complicated because the condensation phenomenon outside the heat exchanger and the internal boiling phenomenon are combined, very few PCCS-related experiments consider both condensation and boiling. Particularly, inner flow phenomena of the PCCS are one of the important factors affected at heat removal capacity because instability is occurred. To investigate heat removal capacity and flow characteristic of the PCCS, experimental facility has been designed only consider boiling effect in the loop not condensation effect. In this study, we investigated inner flow phenomena through heat condition at outside of test section and measure hydraulic parameters such as pressure, temperature, etc.

2. Experimental facility

As shown in Fig. 1, the experimental facility is comprised with two loops, one is hot loop for heat source (red line) the other is the natural circulation loop (blue line) for simulating the PCCS. The hot loop was designed to simulate the inner temperature condition of containment building during post-accident using water for preventing the condensation effect. Working fluid is heated up by auxiliary / main heater which controlled by PID controller and flow through pressurized vessel, heat exchanger, auxiliary pressurized vessel by magnetic pump. The maximum pressure of the hot loop is designed as 10 bar and for preventing secure accident relief valves which act at 9 bar were installed at the top of auxiliary pressurized vessel and mini pressurized vessel. The total length of pressurized vessel is 3.0 m and inner diameter is 0.3 m. The experimental

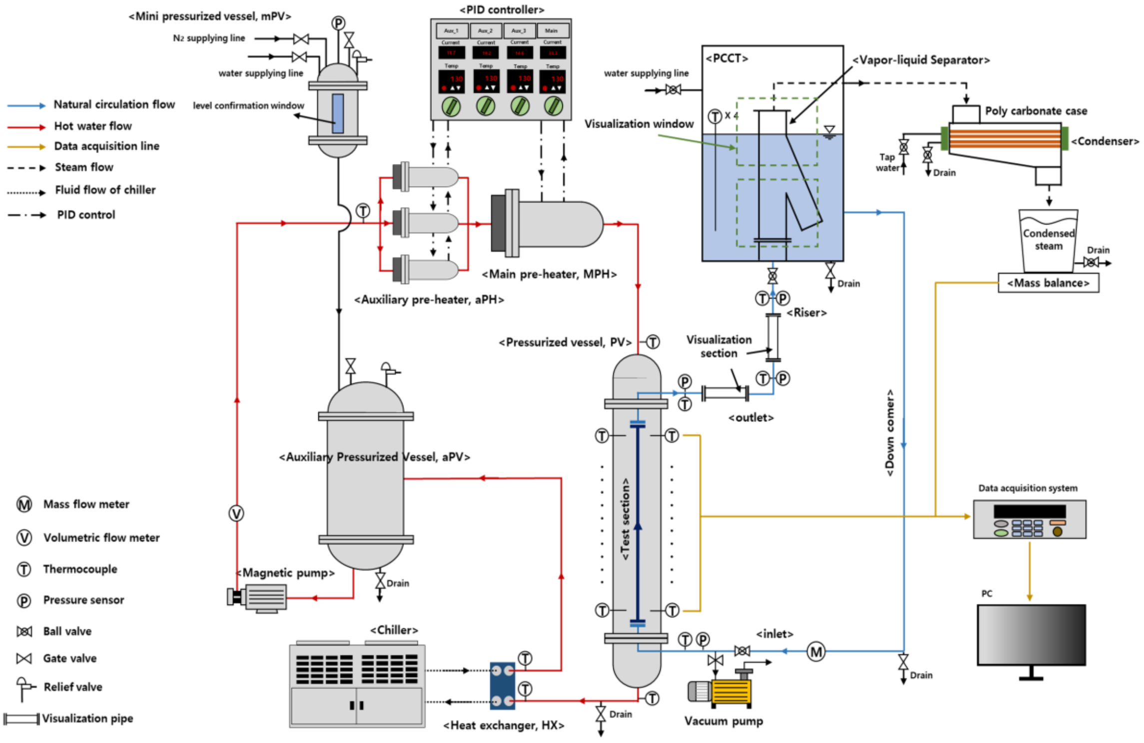

Fig. 1 Schematic of experimental facility

temperature condition is set as under 150℃ and for preventing boiling phenomena at the hot loop the experimental pressure condition is set from 6 to 8 bar. The turbine flow meter, pressure transmitter and K-type thermocouples were installed for measuring flow rate, loop pressure and temperature of fluid. The natural circulation loop is consisted with Passive Containment Cooling Tank (PCCT), down comer, test section, horizontal outlet, riser and vapor-liquid separator. The PCCT have 1 x 1 x 1.8 m (Width x Depth x Height) dimensions and inner diameter of the loop lines and test section have 42.6 mm and 38.3 mm, respectively. The height of the vapor-liquid separator which made of polycarbonate for visualization is 1000 mm and square cross-section with 150 mm of side length. The total length of the heat exchanging pipe is 3.0 m with 2.7 m of vertical test section and 0.3 m of vending lines. The visualization sections are constructed at horizontal outlet and riser for investigating flow phenomena. Water was occupied 1 m length of the PCCT, and total water level is set as 5.1 m from inlet line. For analyzing thermal-hydraulic phenomena temperature and pressure were measured at the inlet, horizontal outlet (out1), bottom part of riser (out2) and upper part of riser (out3).

3. Test results

Two kinds of experimental cases were conducted depending on temperature of water of the hot loop.

Case	Temperature condition [℃]	Heat flux [kW/m^2]	Water level [m]
LH	128.9	12.53	5.1
HH	146.6	29.62	5.1

Table. 1 Description of the experimental cases

Table. 1 represent information of experimental cases as Low Heat (LH) and High Heat (HH) depending on temperature condition of the hot loop. The heat is calculated by mass flow rate, inlet & outlet temperature of pressurized vessel and surface area of heat exchanging pipe. During experiment boiling and flashing phenomena were occurred in the natural circulation loop. The experiment is conducted as a steady-state condition at the atmospheric pressure and inlet temperature is set from 95 to 99℃. As a result, flow instability was induced both experimental cases shown in Fig. 2.

3.1 Mass flow rate

The mass flow rate was measured before working fluid entered heat exchanging pipe by coriolis flow meter. In the LH case (blue line), oscillation frequency represents about 40 – 45 s and there exist incubation period for increasing flow rate because it is difficult to make vapor immediately after subcooled water enter the heat exchanging pipe. On the other hand, in the HH case, there not exist incubation period because of high heat flux and it shows not only short oscillation frequency about 10 – 15 s but also high mass flow rate. In addition, it is often seen that the mass flow rate rises before reaching the lowest point due to rapid vapor generation due to high heat. The results not represented negative flow rate in both cases because exit line of riser is linked with the PCCT.

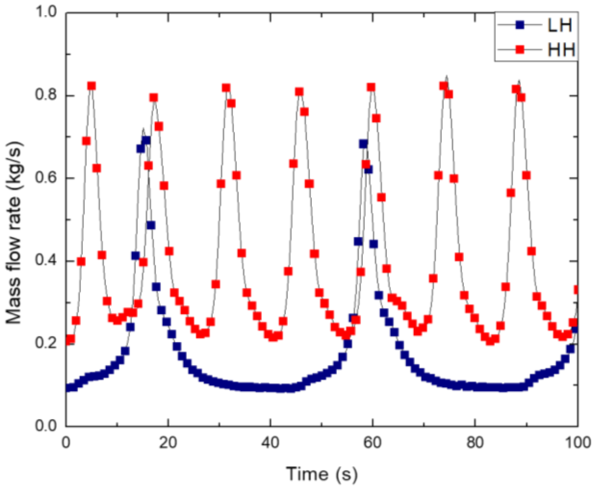

Fig. 2 Mass flow rate of experimental cases

3.2 Main factor increasing the mass flow rate

To identify what factor will be induce flow instability and where will be occurred, pressure difference each point were compared. Fig. 3 represent mass flow rate (black line), pressure difference between out1 and out2 (orange line) and pressure difference between out1 and out3 (green line) in the LH case. When the flow

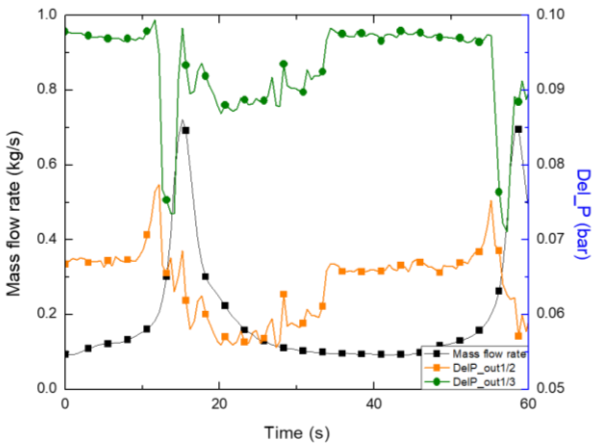

Fig. 3 Mass flow rate and pressure characteristic in LH case

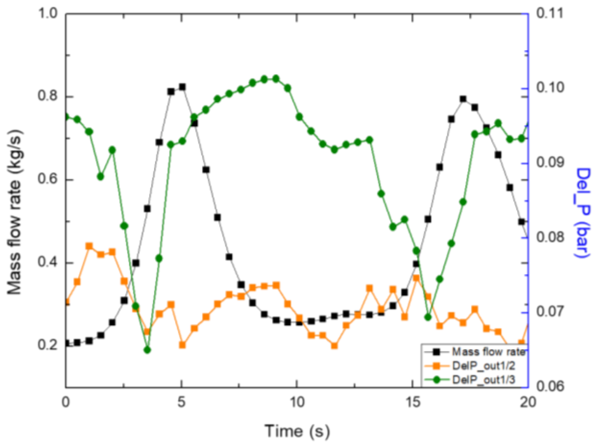

Fig. 4 Mass flow rate and pressure characteristic in HH case

increases dramatically, pressure difference between out1 and 2 getting increase than out 1 and 3. It means that density of fluid between out2 and 3 decrease because of flashing phenomena and vapor from horizontal outlet and it induced flow increasement mainly. Fig. 4 represent mass flow rate, pressure difference of HH case. Although it shows few different tendencies compared with Fig. 3, main factor of inducing flow increasement is same. In this case, vapor can stack directly after stop the flow excursion and it prevent mass flow rate reach at minimum point.

3.3 Visualization

Fig. 5 shows the visualization data of the LH case as one oscillation period. Firstly, generated vapors from heat exchanger tube were stacked along horizontal outlet (0s) and some vapor pass to riser because more vapors stack time by time (6.67s). A fairly large amount of vapor was existed in riser before occurring dramatic the flow increasement (10.0s), soon, flow excursion was occurred (10.7s). The flow excursion holds for a few seconds (11.67s) and the vapors were diminished from outlet horizontal and riser gradually (12.67s). It also proofs that fluid density decrease between point of out 2 and 3 caused by flashing and boiling phenomena and it is main factor of flow excursion.

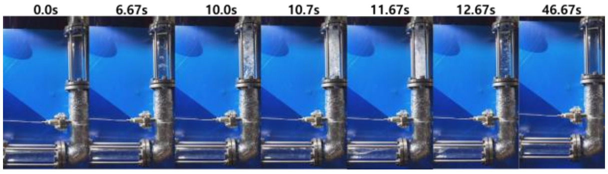

Fig. 5 Visualization data of flow oscillation in LH case

Fig. 6 shows the visualization data of the HH case. The basic mechanism of flow excursion is same with LH case; however, it presents more short oscillation period because that case is transferred more heat from the hot loop than LH case. In addition, as mentioned above, it presents the vapors were stacked in horizontal outlet before the mass flow rate reached minimum value.

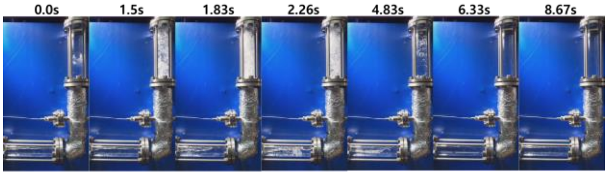

Fig. 6 Visualization data of flow oscillation in HH case

4. Conclusions

The characteristic of two-phase natural circulation loop which simulate the PCCS was investigated through single-heat exchanger tube at temperature condition. For simulating the PCCS, we constructed the hot loop for heat source by hot water and the natural circulation loop. The mass flow rate and pressure difference between selected point were measured according to experimental cases. As temperature condition of hot loop more increase, the flow oscillation period more shorter and flow rate more increase. Finally, we inferred what is the main factor which occurred flow excursion through pressure difference data at each point and the visualization data well proofed the inference.

Acknowledgments

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