Reflood experiments in a 2x2 rod bundle with 90% partial blocked region

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1. Introduction

During the reflood phase of a large break loss-of-coolant accident (LBLOCA), the fuel rods can ballooned and rearranged under uncovered core conditions, and the ballooned fuel rods induce a reduction of the flow passage of the subchannel. The blockage effect causes flow redistribution and affects the transient heat transfer behavior of the fuel rods. An experimental program was launched at KAERI in 2011 to understand the related phenomena and evaluate the coolability of the fuel rods under certain circumstances. The program is divided into two large group tests. The effect of the blockage characteristics are investigated in the first experiment with a 2x2 rod bundle test facility, and the coolability of the ballooned fuel rods considering fuel relocation will be evaluated later in a 5x5 test facility. The blockage characteristics are greatly dependent on the blockage characteristics (blockage representativity, blockage ratio, blockage length, blockage shape, and blockage configuration) and the coolant conditions (flow, system pressure, and inlet temperature). In this study, some results of the first experiments will be presented as a parametric study. The coolability was investigated by varying reflood rates, and the results were discussed through the transient profiles of temperature along the elevation of the rods to investigate the quench phenomena.

2. Experiments

The experiments were carried out in a 2x2 test facility. A schematic diagram of the test section is shown in Fig. 1. The fuel rods were simulated using electrically-heating rods. The heated length is 1.8m, and the diameter and pitch of the heater rods are about two times larger than that of a conventional PWR reactor. The uniform electrical power can be supplied to the heater rods, and four spacer grids without mixing vane were assembled to the test section to prevent a drastic temperature increase during the experiments. The ballooned shape of the fuel rods was simulated by superimposing the blockage simulator onto the heat rods, as shown in Fig. 2. The partial blockage ratio at the center of blockage simulator was 90%. To measure the transient temperature histories in the blockage region, 7 T/Cs were embedded on the outer surface of the blockage simulator. In addition, 40 T/Cs were installed on the surfaces of 4 heater rods. It was noted that the blockage simulators were installed on the same elevation without considering the bypass flow region between the adjacent fuel rods, owing to the inherent geometrical restriction of the 2x2 test facility.

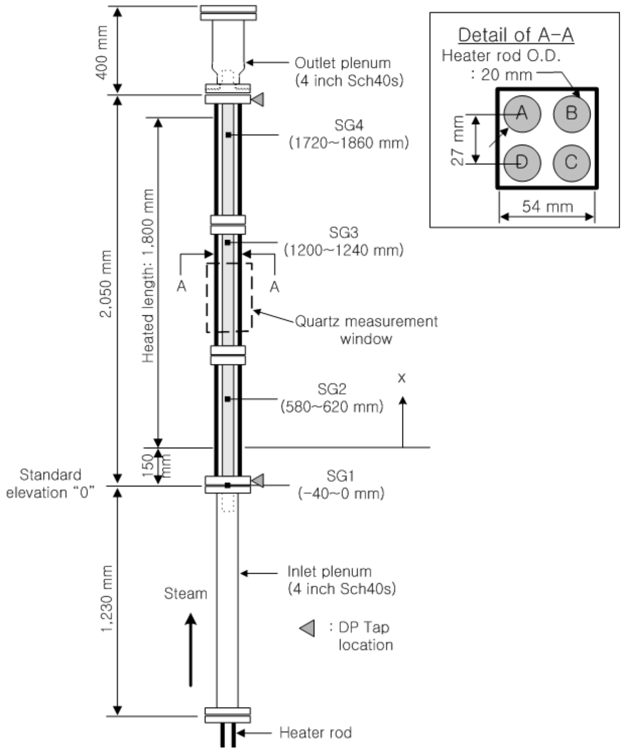

Fig. 1 Schematic diagram of the test section

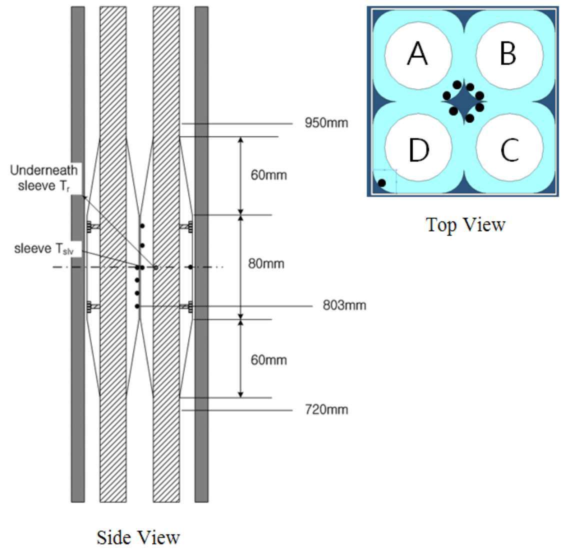

Fig. 2 Configuration of the blockage simulator

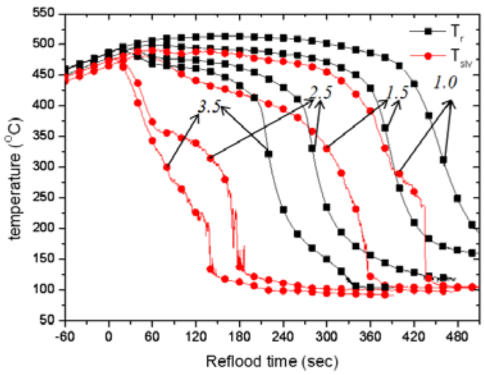

Fig. 4 Transient temperature profiles at 803mm

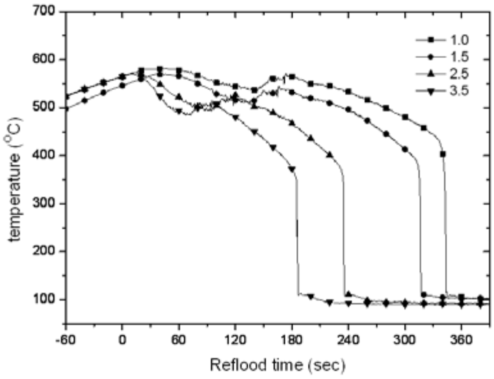

Fig. 5 Transient temperature profiles at 720mm

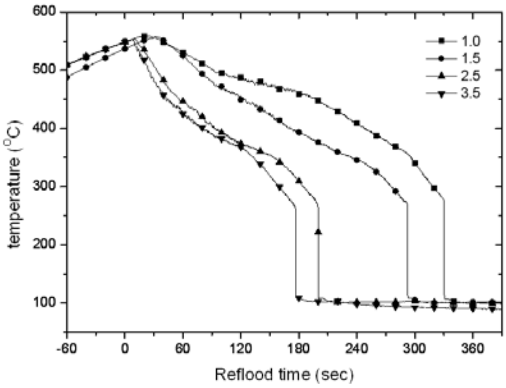

Fig. 6 Transient temperature profiles at 950mm

3. Results

The experiments were carried out for various reflood rates ranging from 1.0 to 3.5 cm/s, and the other main parameters were maintained under the same condition. The system pressure, inlet subcooling temperature, and power were about 0.15Mpa, 40℃, and 1.5kW/m, respectively. The transient temperature was measured along the elevation, and the results are shown in Figs. 4 and 5. As shown in Fig. 4, the sleeve and rod temperatures were measured simultaneously at the same elevation. The rod temperature is always higher than the sleeve temperature, since the rewetting of the sleeves occurs earlier than the heater rods. The quench time based on the sleeve temperature cannot be determined exactly owing to the fluctuation in the quenching period. However, it was obvious that the quenching occurred earlier when the reflood rates were higher than 2.54 cm/s. The calculated quench time at the upstream and downstream of the blockage region are shown in Table 1. The quenching occurred earlier at the upstream of the blockage region, and this tendency was coincident with the previous FLECHT test [1]. As mentioned earlier, the blockage simulator was arranged without considering the bypass region, so the mass flow rate in the blockage subchannel was increased in proportion to the reduced flow area. It was interesting that the quenching time at the low reflood rate (1.5 and 1.0 cm/s) was not greatly reduced even with the increased mass flow rates, as shown in Fig. 4. The coolability at the blockage region was determined by the combined effect of the complex two-phase heat transfer and various hydraulic conditions, such as the flow redistribution around the blockage region and droplet behavior, which are also dependent on the blockage characteristics. The effect of the droplet impact on the blockage and droplet fragmentation should be carefully examined together as a future work, although the droplet behavior was not considered in this study.

Table 1. Comparison of quench time

$V_{reflood}$[cm/s] / elevation[mm]	720	950
1.0 cm/s	342	329
1.5 cm/s	316	291
2.5 cm/s	234	199
3.5 cm/s	184	176

4. Conclusion

As a parametric study, several tests were performed in the 2x2 rod bundle test facility to investigate the effect of the blockage region by varying the reflood rates. To evaluate the effect on the quench phenomena, the quench time was calculated and compared along with the elevation and reflood rates. When the reflood rates were higher than 2.5cm/s, the coolability at the blockage region was enhanced contrary to the results at the low reflood rates. As a conclusion, the coolability at the low reflood rates should be carefully examined for a safety analysis and further investigated considering the droplet behavior.

ACKNOWLEDGMENTS

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[1] C. Grandjean, A State-of-the-Art Review of Past Programs Devoted to Fuel Behavior Under Loca Conditions, Part Two. Impact of clad swelling upon assembly cooling, Technical Report SEMCA-2006-183, IRSN, 2005.