Transient heat transfer behavior during reflood phase in a 2x2 ballooned rod bundle

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1. Introduction

If the fuel rods are ballooned or rearranged under uncovered core conditions, the ballooned fuel rods induce a reduction of the flow passage of the sub-channel, and causes flow redistribution which affects the transient heat transfer behavior of the fuel rods. As a result, the coolability of the ballooned region is entirely different with that of the normal ones. Therefore, in this study, the transient heat transfer behavior during the reflood phase of ballooned fuel rods was experimentally investigated in a 2x2 rod bundle test facility. The coolability depends greatly on the blockage characteristics (blockage ratio, blockage length, blockage shape, and blockage configuration) and the system conditions of the test facility (flow, system pressure, and inlet temperature) [1]. Among them, the blockage ratio effect on the coolabiltiy is carefully examined varying the reflood rate in the present study, since the blockage ratio plays a significant role on the coolability under the low reflood rate condition (2.5 cm/s). The test results were analyzed with the transient temperature profiles of the fuel rods and the local heat transfer coefficient calculated using a 1-D cylindrical coordinates FVM (Finite-Volume-Method) code.

2. Test facility and blockage simulator

The experiments were performed in the 2x2 rod test facility, as shown in Fig. 1. Four electrically-heating rods which have 20 mm in diameter and are arranged in a square array with a 27 mm pitch were used, and the total heated length is 1.8m. A uniform electrical power is supplied to the heater rods, and four spacer grids without mixing vane were assembled to the rod bundle to prevent a drastic temperature increase during the experiments.

The ballooned shape of the fuel rods was simulated by a blockage simulator, as shown in Fig. 2. Two types of the blockage simulator were designed which have 90% and 62% blockage ratio at the center region with same inlet/outlet taper length. Ten thermocouples were installed on the outer surfaces of each heater rod to measure the transient temperature histories on the heater rods. Blockage simulators were placed between 735 mm and 935 mm from the bottom of the heated length, since the effect of the second and third spacer grids is diminished in that region. The details of the 2x2 rod bundle test facility were described in [2].

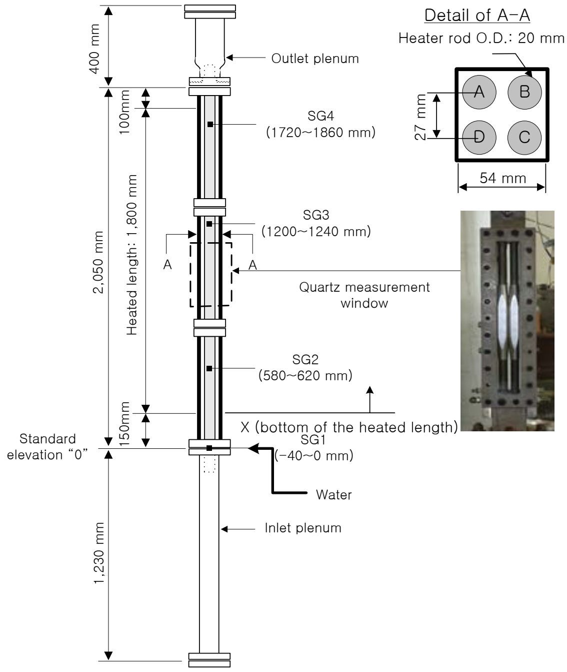


Fig. 1 Schematic diagram of the test section

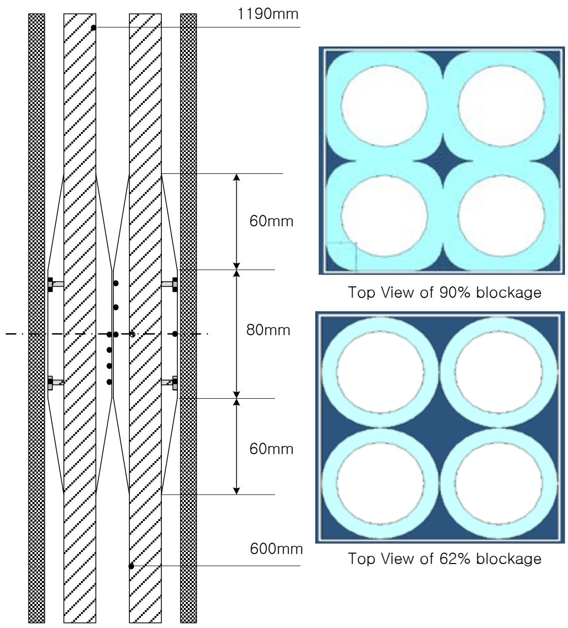
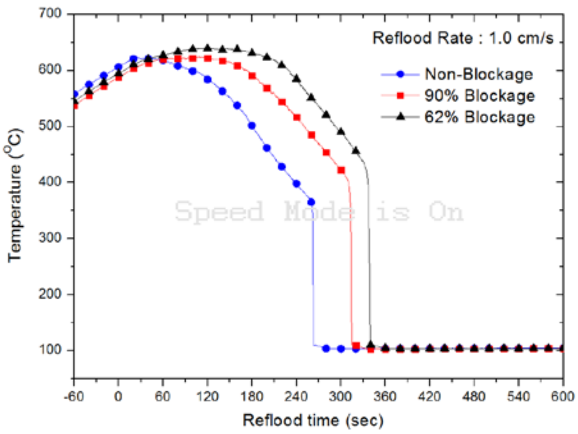
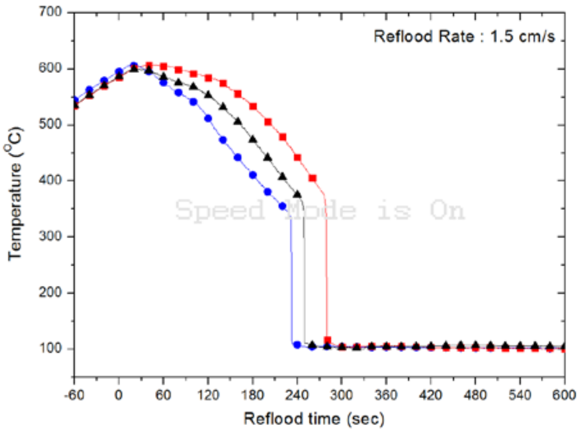


Fig. 2 Configuration of the blockage simulator



(a)



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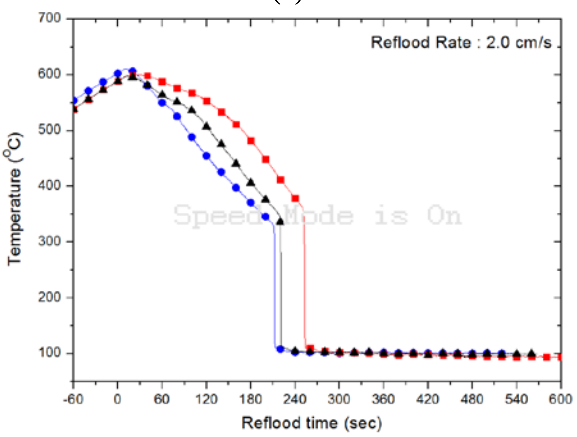

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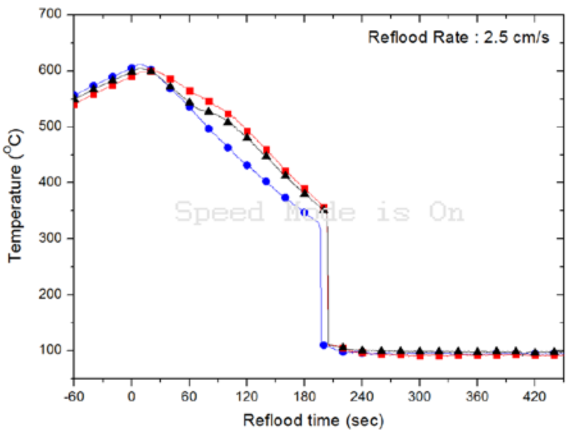
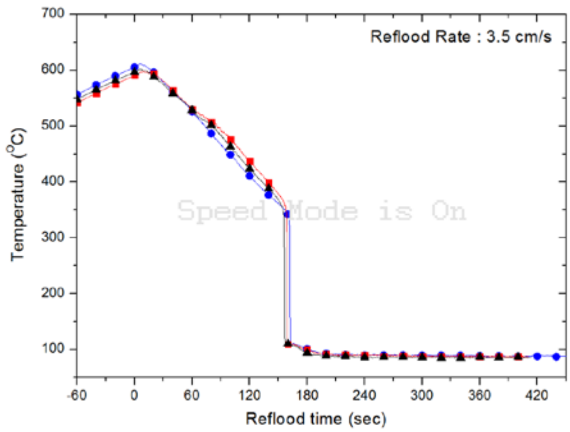


(d)



(e)

Fig. 3 Transient temperature profiles for the reflood rates at the upstream region (600 mm)

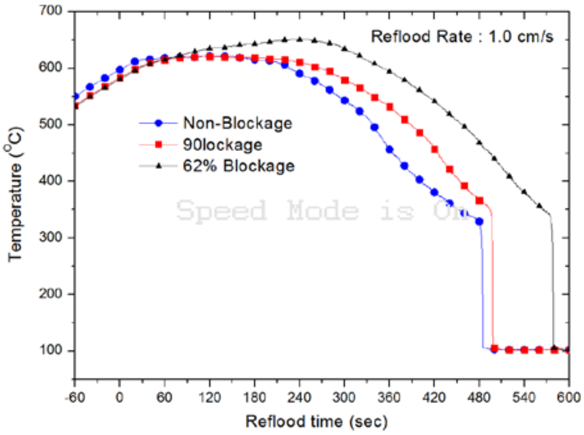
3. Test results

Forced reflood tests were carried out for the non-blockage, 90% blockage, and 62% blockage conditions with various reflood rates ranging from 1.0 to 3.5 cm/s. The system pressure, inlet subcooling temperature, and power were about 0.101Mpa, 50℃, and 1.5kW/m, respectively. The transient temperature profiles at the upstream (600 mm) and the downstream (1190 mm) regions were measured, and the results were shown in Figs. 3 and 4, respectively.

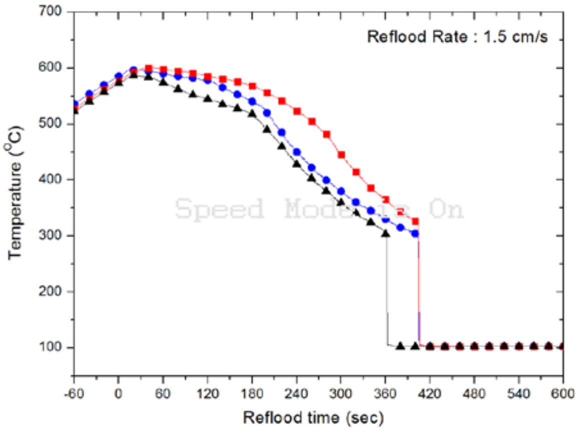
As shown in Fig. 3 (d) and (e), when the reflood rates are more than 2.5 cm/s, there are not any great difference between the results of 90% and 62% blockage ratio. However, the coolability decreases with decreasing the reflood rate comparing with the results of non-blockage case. As shown in Fig. 2, the flow passage is reduced owing to the blockage simulator arranged without the bypass region. The reduced flow area in the subchannel induces a large flow resistance, so the fluid velocity decreases in the blocked region. As a result, the coolability decreases with increasing the blockage ratio.

In the downstream region, as shown in Fig. 4, the coolability was enhanced as the reflood rate increases, regardless the blockage ratio, because of the intensification of the turbulence intensity and the increase of the mass flow rate [2, 3] in the downstream region. It was noted that the cooling at the downstream region is not enhanced anymore even with the 90% blockage ratio when the reflood rates are more than 2.5 cm/s, since the downstream region became fully turbulent. However, the heat transfer enhancement shows a slowdown as the reflood rates decrease, as shown in Fig. 4 (a) to (c).

On the other hand, it is interesting that the coolability for the 62% blockage case is greatly reduced compared with the results of 90% and non-blockage cases, as shown in Fig. 3 (a) and Fig. 4 (a). This tendency can be confirmed in Fig. 5 which shows the



(a)



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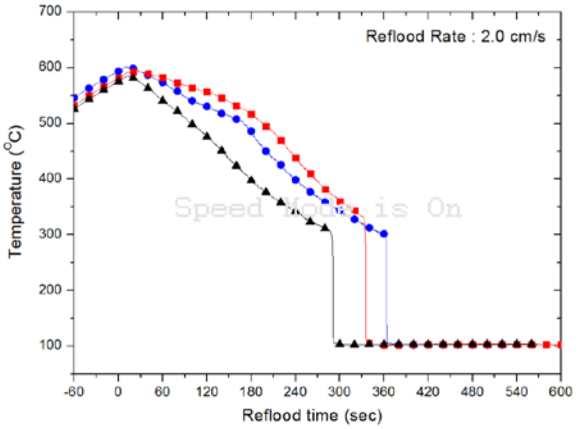
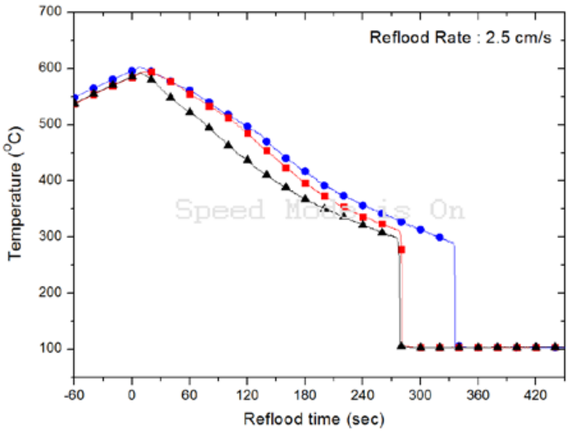
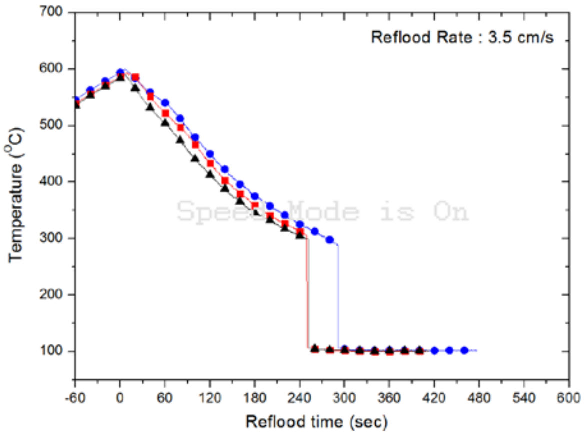


(c)



(d)



(e)

Fig. 4 Transient temperature profiles for the reflood rates at the downstream region (1190 mm)

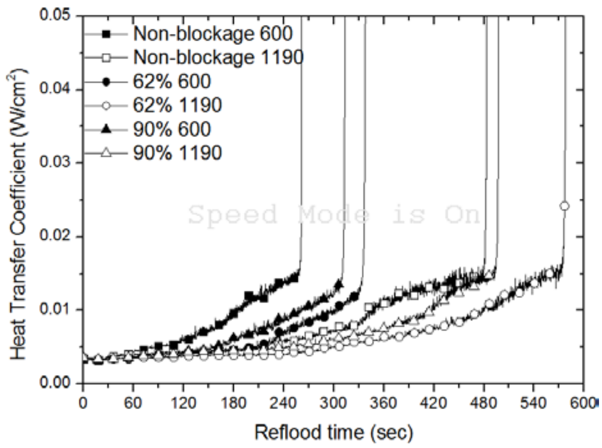


Fig. 5 Local heat transfer coefficient for 1.0 cm/s

local heat transfer coefficients at the upstream and downstream region when the reflood rate is 1.0 cm/s.

The heat transfer coefficient for the 62% blockage ratio is about half of the non-blockage case. This result may be explained with considering the two-phase heat transfer and the interaction with the fluid flow, since the quenching phenomena depend on a flow regime and droplet behavior. Therefore, as a future work, the droplet measurement is indispensable to understand the quench phenomena.

4. Conclusion

Forced reflood tests with various reflood rates were performed to understand the transient heat transfer behavior and to investigate the influence of the blockage ratio on the coolability in the 2x2 rod bundle test facility. The transient temperature profiles and the local heat transfer coefficients at the upstream and downstream region of the blockage simulator were examined for non-blockage, 90% blockage, and 62% blockage conditions. In the downstream region, the coolability was greatly enhanced except for a low reflood rate (1.0 cm/s). In the upstream region, the cooling performance decreased smoothly with decreasing the reflood rate. When the reflood rate is 1.0 cm/s, the coolabilities at the both upstream and downstream region were significantly reduced regardless of the blockage ratio. As a conclusion, the coolability at the low reflood rate (1.0 cm/s) should be carefully examined with the droplet behavior as a future work.

ACKNOWLEDGMENTS

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REFERENCES

[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.

[2] K. Kim, et al., Coolability of the Ballooned Region in a 2x2 Rod Bundle, LWR Fuel Performance Meeting, Top Fuel 2013, Sept.15-19, 2013, Charlotte, NC.

[3] K. Kim, et al., Effect of Flow Blockage on the Coolability during Reflood in a 2x2 Rod Bundle, Science and Technology of Nuclear Installations, Vol. 2014, Article ID 247862, 2014.