Experiments on Reflood with Deformed Fuel Rods during SB-MB LOCA in PWR

Seung-Hyun Hong *, Jong-Kuk Park, Young-Jung Youn, Hae Seob Choi, Sang-Ki Moon
Korea Atomic Energy Research Institute
Daedeok-daero 989-111, Yuseong-gu, Daejeon, 305-353, Republic of Korea
hongsh@kaeri.re.kr; jongrok@kaeri.re.kr; jkpark2@kaeri.re.kr; yjyoun1@kaeri.re.kr; hschoi@kaeri.re.kr ; skmoon@kaeri.re.kr

1. Introduction

Depending on the size of break on the cold legs and its phenomenology on the reactor despondence, the postulated LOCA(Loss Of coolant Accident) can be categorized into LB(Large Break), MB(Medium Break), and SB(Small Break) LOCA scenarios, respectively. In SB and MB LOCA cases, the coolant gradually leaks out through the breaks so that the reactor core could become uncovered leading to steep increase in fuel temperature. After reaching a set point, the Emergency Core Cooling (ECC) system is triggered and cold water is injected into the reactor core as bottom reflood. Since deformation of the fuel rods could be also encountered during SB and MB LOCA conditions, several reflood experiments were conducted to investigate the effect of deformed fuel rod in various flow conditions covered the SB and MB LOCA cases. Experimental results were analyzed and compared to those of non-deformed fuel rods experiments.

2. Theoretical background

Experiments on reflooding phase under low, medium and high pressure conditions with intact fuel rods have been carried out in different experimental facilities in KAERI [1-3]. The well-known THETIS experimental reports presented the SBLOCA simulation experiments. The experimental data was constructed into database by the interaction with both water and steam during water level with a little waves lapping on the fuel rod with boiling heat transfer[4]. The JAERI and ROSA-IV reports [5,6] investigated the reflooding phenomena on high pressure and temperature conditions in the SB LOCA using non-deformed fuel rod. IRSN carried out reflooding experiments to particularly analyze the phenomena from LB LOCA to SB LOCA[7]. Table 1 summarizes the test conditions of the aforementioned experiments.

Table 1 Experimental condition for several facilities

	THETIS	JAERI	ROSA -IV	IRSN
Rod bundle matrix(flow blockage)	7×7(4×4)	4×4	5×5	7×7
Heater length (m)	3.58	3.71	-	-
Pressure (bar)	2-40	20-80	5-120	1-40
Power (kW)	10-150	0-800	-	-
Initial level (m)	1.07-3.22	-	-	-
Initial temperature(°C)	-	700	0-650	600-700

3. Experimental methods

Fig.1 shows the schematic diagram of the test section in the present experiments.

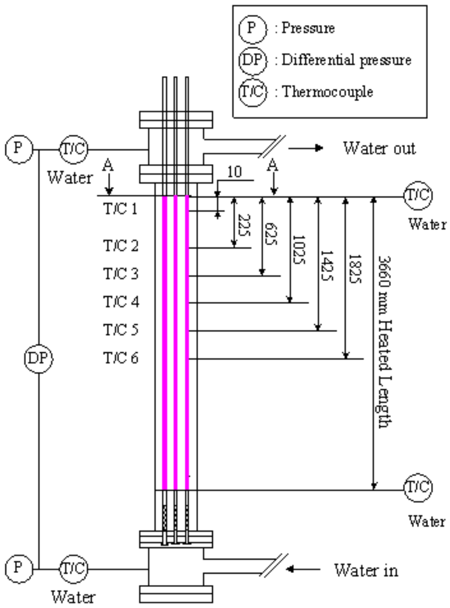

Figure 1. Schematic diagram for the test section.

The test section consists of 3 by 3 Inconnel 600 heater rods arranged in the square lattice array as shown in Fig. 2. Thermocouples were located at six different elevations on each fuel rod to measure the rod temperature. The coolant temperature can be measured by insertion of thermocouple to the subchannel centers. The test conditions cover wide ranges of the main test parameters such as pressure from 10 to 80 bar, the total power of 10-40 kW, the initial water level of 0-1.5 m, the reflooding rate of 1-7 cm/s, the initial temperature of

500-700 °C, and the inlet sub-cooling from 40 to 110 °C.

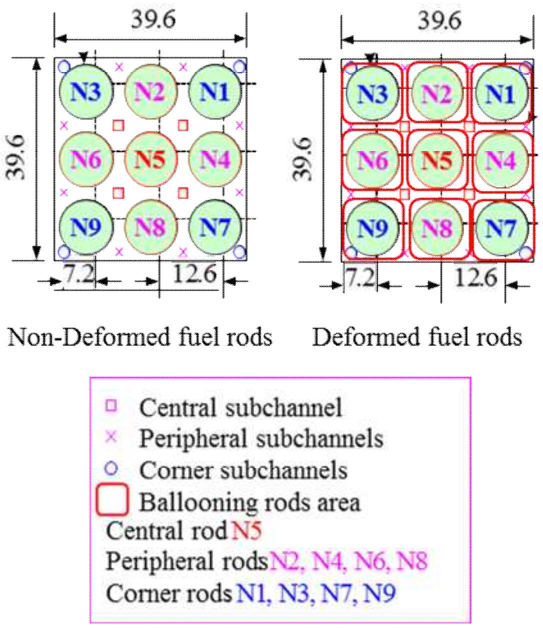

Figure 2. Geometry of 3x3 rod bundle

3. Experimental results

3.1. Reflooding behavior in different flow conditions

The experimental results show different reflooding conditions depending on changes of the main test parameters. Fig. 3 shows that higher peak cladding temperature was obtained in case of higher reflooding rate, initial level, initial temperature, pressure, total power and inlet subcooling compared with those of lower flow conditions.

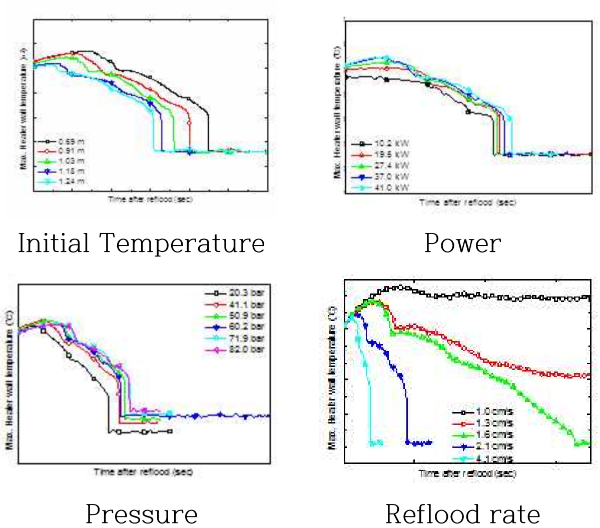

Figure 3. Influence of flow conditions on peak cladding temperature

3.2. Blockage effect

As shown in Fig. 4, the quenching temperature and quenching time had a different between deformed and non-deformed fuel rod. The results can be explained by blockage effect. The blockage which located at the middle elevation of the rod decreased the local temperature and enhanced the heat transfer within following 2 different effects. First, the flow velocity increased to conserve the cross-sectional flow rate on every elevation. Second, the entrained droplets also enhanced the local heat transfer at the heated wall and the steam around the blockage region. Owing to the blockage region, the droplets have more collided with the wall and the steam. Its phenomena could be seen as Fig. 5.

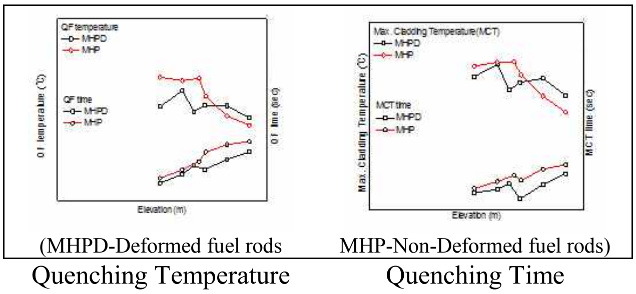

Figure 4 Comparisons between MHP and MHPD

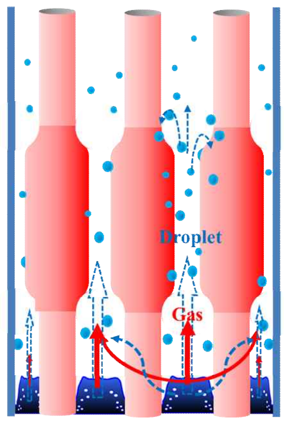

Figure 5 Flow distributions on the blockage region

REFERENCES

[1] J. Kim, S.-K. Moon, S. Cho, J.-K. Park, Rewetting Characteristics in 6 x 6 Rod Bundle During the Reflood. Phase, LWR Fuel Performance Meeting TopFuel 2013, Charlotte, NC, US, September 15 - 19, 2013

[2] K. Kim, B. Kim, Y. Youn, H. Choi, S. Moon, C. Song, Effect Of Flow Blockage On The Coolability During Reflood In A 2x2 Rod Bundle, Science And Technology Of Nuclear Installations, Volume 2014, Article ID 247862, 2014

[3] J. Kim, J.-K. Park, Y.-J. Youn, H.S. Choi, S.-K. Moon, Different reflood characteristics between intact rod bundle

and ballooned rod bundle, The Ninth Korea-Japan Symposium on Nuclear Thermal Hydraulics and Safety, Buyeo, Korea, November 16-19, 2014

[4] Dowitt, D, et. all, The THETIS 80% blocked cluster experiment-part 5 level swell experiments, AEEW1767, AEE Winfrith, 1984.

[5] Tadashi Iguchi, et. al. Effect of heat input on minimum heat flux temperature observed at reflood experiment with 4x4 bundle test section under high-pressure, ICONE-8539, Proceedings of ICONE 8, 2000.

[6] KOIZUMI, Y., et. al. High-pressure reflooding experiments of multi-rod bundle at ROSA-IV TPTF, Nuclear Engineering and Design 120, 301-310, 1990.

[7] Grandjean, C., 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, 2006.