Rewetting phenomena in a 6x6 rod bundle during a reflood phase

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1. Introduction

A series of experimental tests were carried out to investigate the rewetting characteristics in a 6x6 rod bundle during the reflood phase. The ranges of experimental parameters are 2~6 cm/s of a flooding velocity, 20~80 ^{o}C of a inlet subcooling temperature, 0.2 ~ 0.6 MPa of a system pressure and 500~700 ^{o}C of an initial wall temperature. In a single rod reflood case performed as a precursory study, the dominant flow regime near the downstream of a quench front is an inverted annular film boiling regardless of flooding velocity. However, the flow regimes in the 6x6 rod bundle geometry are observed as an inverted annular flow and dispersed flow and they are closely related to the flooding velocity. The flooding rate also governs the entrainment rate of droplet in the test section during the reflood. Superheated steam temperature was measured at several locations of subchannel in the rod bundle and compared with the corresponding temperature of the rods. Finally, trends of the quench temperature with a variation of the test parameters are presented and compared with previous correlation.

2. Descriptions on the test

The 6x6 rod bundle reflood test facility was named ATHER (facility for **A**dvanced **T**hermal **H**ydraulic **E**valuation of **R**eflood phenomena). ATHER consisted of a test section, separating system for measuring the amount of entrained liquid droplet, pressure oscillation damping system to control the system pressure during preparation and testing period, coolant supply and steam supply system. The detailed descriptions on ATHER and the experimental procedure can be found in Ref. [1].

Table 1 Test matrix of the 6x6 rod bundle reflood test

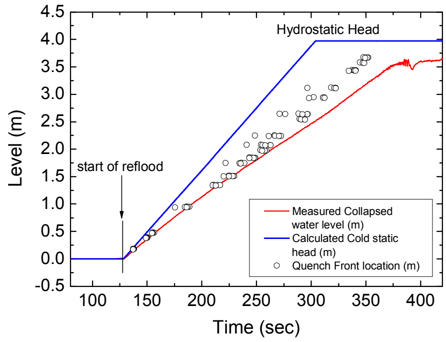
Serial No.	Test ID.	System Pressure (MPa)	Flooding Rate (cm/s)	Max. Initial heater wall Temperature (°C)	Inlet Water Temperature (oC)	Remarks
1	EP 2 2 – 500 30	0.2	2	500	30	10 kW
2	EP 2 2 – 500 80	0.2	2	500	80	
3	EP 2 2 – 600 30	0.2	2	600	30	
4	EP 2 2 – 600 80	0.2	2	600	80	
5	EP 2 2 – 700 30	0.2	2	700	30	
6	EP 2 2 – 700 50	0.2	2	700	50	
7	EP 2 2 – 700 80	0.2	2	700	80	
8	EP 2 4 – 500 30	0.2	4	500	30	
9	EP 2 4 – 600 30	0.2	4	600	30	
10	EP 2 4 – 600 50	0.2	4	600	50	
11	EP 2 4 – 600 80	0.2	4	600	80	
12	EP 2 4 – 700 30	0.2	4	700	30	
13	EP 2 6 – 500 30	0.2	6	500	30	
14	EP 2 6 – 600 30	0.2	6	600	30	
15	EP 2 6 – 600 80	0.2	6	600	80	
16	EP 2 6 – 700 30	0.2	6	700	30	
17	EP 2 6 – 700 50	0.2	6	700	50	
18	EP 2 6 – 700 80	0.2	6	700	80	
19	LP 2 2 – 600 30	0.2	2	600	30	5 kW
20	ZP 2 2 – 600 30	0.2	2	600	30	0 kW
21	LP 2 4 – 600 30	0.2	4	600	30	5 kW
22	ZP 2 4 – 600 30	0.2	4	600	30	0 kW
23	EP 4 2 – 500 30	0.4	2	500	30	
24	EP 4 2 – 600 30	0.4	2	600	30	
25	EP 4 2 – 700 30	0.4	2	700	30	
26	EP 4 2 700 50	0.4	2	700	50	
27	EP 4 2 – 700 80	0.4	2	700	80	
28	EP 4 4 – 600 30	0.4	4	600	30	
29	EP 4 4 – 700 30	0.4	4	700	30	
30	EP 4 6 – 600 30	0.4	6	600	30	
31	EP 4 6 – 700 30	0.4	6	700	30	
32	EP 4 6 – 700 80	0.4	6	700	80	
33	EP 6 2 – 500 30	0.6	2	500	30	
34	EP 6 2 – 600 30	0.6	2	600	30	
35	EP 6 2 – 700 30	0.6	2	700	30	
36	EP 6 2 700 50	0.6	2	700	50	
37	EP 6 2 – 700 80	0.6	2	700	80	
38	EP 6 4 – 600 30	0.6	4	600	30	
39	EP 6 4 – 700 30	0.6	4	700	30	
40	EP 6 6 – 600 30	0.6	6	600	30	
41	EP 6 6 – 700 30	0.6	6	700	30	
42	EP 6 6 – 700 80	0.6	6	700	80	

Table 1 shows the test matrix of the 6x6 reflood test. As can be seen in the table, 19 cases, filled by gray color, were performed among a total of 42 cases. Naming rule of the test ID is that the first two letters is power condition divided into three power levels, and following two digits mean the system pressure (2, 4, 6 bar) and flooding rate (2, 4, 6 cm/s), respectively. Finally the next five digits indicate the initial cladding temperature (500, 600, 700 ^{o}C) and the inlet coolant temperature (30, 50, 80 ^{o}C), respectively.

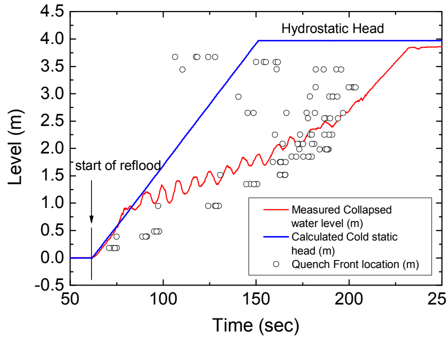
3. Discussions on the experimental results

3.1 Flow regime

Two types of flow regimes were observed depending on the flooding rate. At low flooding rate

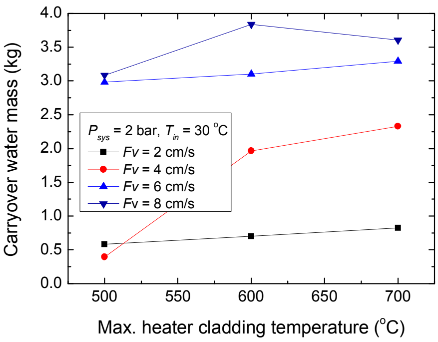


(a) EP42-50030 case

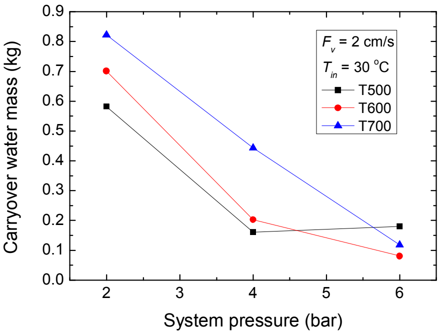


(b) EP24-70030 case

Fig. 1 Behavior of the measured collapsed water level and the quench front location



(a) Effect of the flooding rate



(b) Effect of the system pressure

Fig. 2 Carryover rate of entrained droplet

condition of 2 cm/s, the dominant flow regime is a dispersed flow regime, on the other hand, at a high flooding rate conditions such as 4 and 6 cm/s, an inverted annular flow is generally observed. The dominant flow regime was identified by a comparison of the collapsed water level and the corresponding quench front locations shown in Fig. 1. In the dispersed flow condition (Fig. 1(a)), the quench front level is higher than the collapsed water level and it linearly progresses along the heated section with time. However, in the inverted annular condition, the quench front level is lower than the collapsed level. Moreover, the quench times at the upper part of the test section are faster than those of the middle section. This is mainly due to the effect of a precursory cooling by entrained droplets.

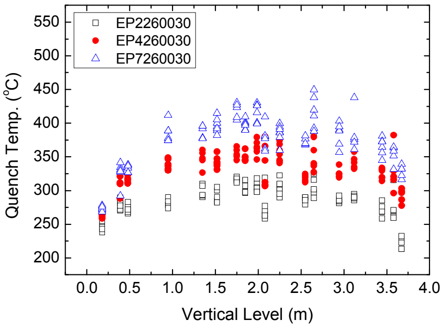


Fig. 3 Behavior of the rewetting temperature along the vertical height with a variation of the test parameters

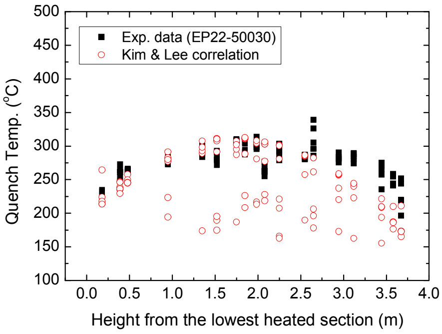


Fig. 4 Comparison of the measured quench temperature with a previous correlation

3.2 Carryover rate of an entrained droplet

The entrainment rates of a droplet were measured by the water level of the carryover tank from the initiation of reflood to the instance when the hydrostatic head reaches its full level. As can be observed in Fig. 2, the carryover rates tend to increase with the increase of the flooding rate and the initial cladding temperature. On the other hand the carryover rate increases with the decrease of the system pressure. The entrainment rates of a droplet substantially affect the cooling at the upper part of the test section.

3.3 Quench behavior

The major parameters affecting the rewetting time are the flooding rate and the initial cladding temperature. The rewetting temperatures, however, are mainly governed by the system pressure as can be observed in Fig. 3, and they are compared with the Kim & Lee correlation summarized in Ref. [2]. The Kim & Lee correlation shows a good agreement with the present data at the low flooding rate, initial cladding temperature, and system pressure condition. However, the correlated values become over-estimated as the flooding rate and the initial cladding temperature increase, and under-estimated as the system pressure increase.

3.4 Superheated steam temperature

The superheated steam temperatures were measured in the low carryover rate condition and compared with the corresponding cladding temperature with time. As the carryover rate increases, the data quality of the measured values becomes poor and the values fall to the saturation temperature level at the instant of the start of the reflood phase.

4. Conclusions

In the present study, the quench behavior such as a flow regime during a reflood phase and the rewetting characteristics with a variation of the test parameters has been investigated. Further tests will be carried out in the near future.

References

[1] Cho, S., Moon, S.-K., Chun, S.-Y., Kim, B.-D., Park, J.-K., and Baek, W.-P., 2005, "Preliminary descriptions on the 6 x 6 reflood test of KAERI, - Part I: Overview of the test facility and matrix," KNS 2005 fall Meeting, Busan, Korea.

[2] Cho, S., Chun, S.-Y., Baek, W.-P., Chung, M.-K., 2005, "Spacer grid effect during reflood in an annulus flow channel," 11th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11), paper: 287, Avignon, France.