Visualization of Downcomer Boiling Phenomena During the LBLOCA Reflood Phase in the APR1400

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1. Introduction

As one of the advanced design features of the Korean advanced power reactor (APR1400), direct vessel injection (DVI) system is adopted instead of conventional cold leg injection (CLI) system. The safety analysis using best estimation codes, such as TRAC-M and RELAP5 showed the driving head to supply emergency core cooling water into the core is highly dependent on the ECC penetration rate in the annulus downcomer and the degree of hydraulic head degradation was arisen by downcomer boiling in the postulated LBLOCA of ARP1400. However, the two codes showed somewhat different quantitative behaviour of the peak cladding temperature(PCT) in the late reflood phase. It is mainly resulted by different thermal hydraulics modelling, especially such as interfacial friction coefficient in the downcomer. The RELAP5 adopts interfacial friction model based on the drift-flux model, however TRAC-M recommends modified Blasius correlation among some adopted interfacial friction models for the lower dowcomer region[1,2]. It gives the different void fraction and then hydraulic head reduction in the downcomer. These results tell us that some investigation is needed on the physical models adopted in the best estimation codes. For this, a separate effect test program for the downcomer boiling phenomena is planned in the KAERI(Korea Atomic Energy Research Institute).

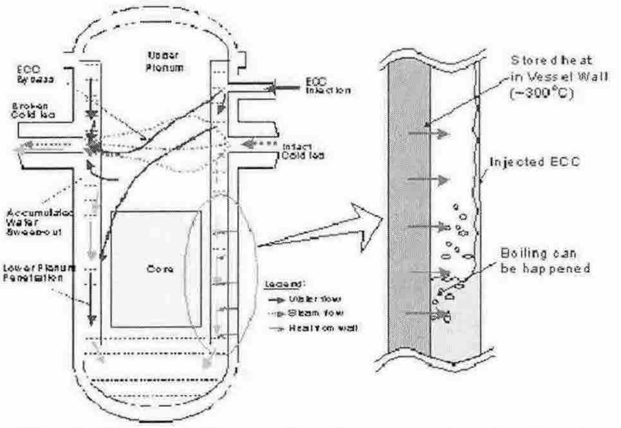


Fig. 1. Thermal Hydraulic Phenomena in the Annulus Downcomer of APR1400 under the LBLOCA Reflood Phase

In this paper, the visual observations and preliminary test results obtained at the DOBO(Downcomer Boiling) facility were introduced.

2. Test Facility

To identify the phasic behaviour experimentally in the downcomer, DOBO (Downcomer Boiling) test facility is constructed simulating lower downcomer region. The test facility was designed by adopting full pressure, full height scaling approach. It also has the same gap size of downcomer with that of the APR1400, however the width is reduced. The scaling ratio of cross sectional area is 1/47.08. For simulating the heat release of the downcomer wall, one face among the four walls of test channel is heated by 207 cartridge heaters. The maximum available heat flux is 10 W/cm^2 which is the heat flux at the time of termination of ECC injection from SIT tanks.

For visual observation of phasic behaviour, transparent glasses are installed on the front and one side walls. The major instruments are two Coriolis mass flow meters for in- and out- flow measurements, eight SMART type differential pressure transmitters for the measurement of water level and axial average void fraction, two SMART type pressure transmitters for the test channel pressures and several K-type TCs for the measurements of fluid temperature.

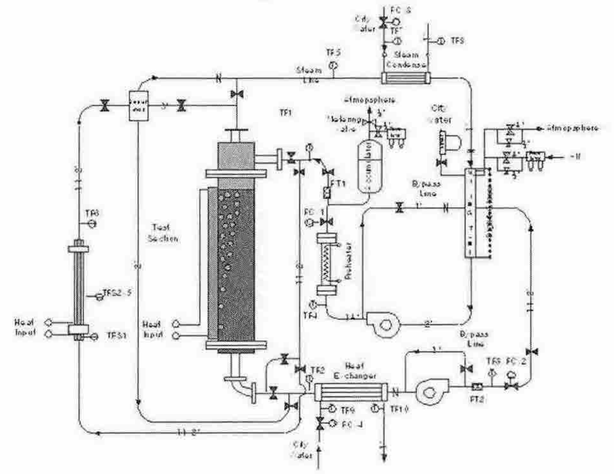


Fig. 2. Schematics of the DOBO Facility

3. Experimental Results

The two cases of preliminary test were performed in the steady state flow conditions and each test condition was obtained from the calculation results of RELAP5 Gamma[3]. The test was limited to the late reflood phase of LBLOCA in which the SIT injection was terminated and water level was maintained below the cold leg. In the test, the heated ECC water simulating core reflood flow was injected through a DVI nozzle located in the top of test section. In the tests, the degree of subcooling of ECC water was 5.7 and 5.8 °C. The water level was maintained constantly by controlling the drain water flow at the bottom. The detail test condition was summarized in the Table 1.

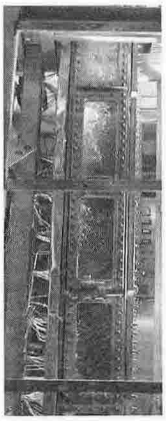
Photo.1 shows the downcomer boiling phenomena in the upper part of test section. The founding from visual observation and test results is summarized as follows;

- Subcooled boiling was occurred and thus distinct bubbly boundary layer was observed in the upper region. It is a typical characterization of subcooled boiling flow. However, it should be considered that the bubble moved upward even though the main water flew downward direction.
- The void fraction decreases as the elevation is low as in the Fig.1. It is resulted by the increase of hydrostatic head in the lower region and then increase of subcooled margin.
- The bubbly boundary layer thickness becomes thicker as the heat flux increases. It is natural because the bubble generation rate increases as the heat flux increases.
- In the mid region of test section, cap bubbles as well as small bubbles were observed even though the void fraction was less than few percent and they slide up along the wall.
- In the lower region of test section, there was no significant void formation and thus average void fraction was negligible.

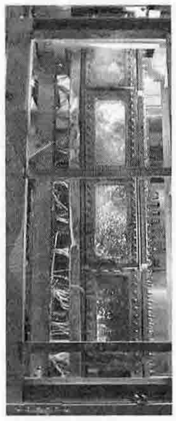
As in the Fig.1, the channel average void fraction is small and thus the degradation of hydrostatic head for the core reflooding is not significant in the present the two test conditions. The tests also showed that the degrees of subcooling in the bottom of test section are 5.63 °C and 4.75 °C in the Case 1 and Case 2,respectively.

Table 1. Experimental Condition

Parameter	Case1	Case2
ECC Temperature(°C)	108.7	108.5
Pressure at Top(kPa)	163.6	169.0.
ECC Injection Flow(kg/s)	1.26	1.27
Heat Flux(W/cm^2)	5.02	6.96



(a) Case 1



(b) Case 2

Photo1. Photograph of Downcomer Boiling

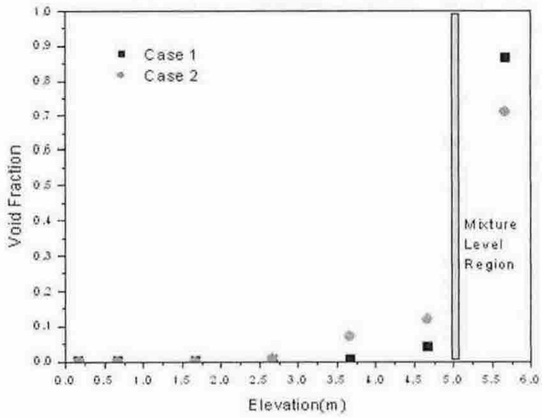


Fig. 3. Axial Void Fraction Distribution

4. Conclusion

As the first step to resolve the downcomer boiling phenomena in the reflood phase of postulated LBLOCA, preliminary test was carried in the DOBO facility. In the test, the count-current subcooled boiling flow was observed. The test showed the channel average void fraction was small and so the reduction of hydraulic head for the core reflood is not severe in the present test condition.

Acknowledgment

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