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Characteristics of Bubble Behaviors in the Downcomer Boiling of APR1400 and Evaluation of Interfacial Friction Models in Safety Analysis Codes

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1. Introduction

Downcomer boiling phenomena in a conventional pressurized water reactor have an important effect on the transient behavior of a postulated large-break LOCA (LBLOCA), because it can degrade the hydraulic head of the coolant in the downcomer and consequently affect the reflood flow rate for core cooling. To investigate the thermal hydraulic behavior in the downcomer region of the APR1400, a test program for the downcomer boiling is being progressed in the reflood phase of a postulated LBLOCA[1]. For this, the test facility was designed as a one side heated rectangular test section which adopts a full-pressure, full-height, and full-size downcomer-gap approach, but with the circumferential length reduced 47.08-fold. The test was performed by dividing into two-phases: (I) visual observation and acquisition of the global two-phase flow parameters and (II) measurement of the local two-phase flow parameters. The Phase-I test showed that 1) occurrence of countercurrent subcooled boiling flow, 2) the creation of a distinct bubble boundary layer whose thickness varied dramatically with the applied heat flux, 3) small channel average void fraction and thus the reduction of the hydraulic head for the core reflood was not too severe in the present test condition, 4) subcooling of 4.3–5.5^{o}C at the bottom of the test section.

However, the information on the internal flow structure of two-phase flow which is required for the evaluation and development of thermal hydraulics models in best estimation codes, are lack in the Phase-I. And thus, measurement of local two-phase flow parameters was tried in the Phase-II. In the present paper, the results of Phase-I and some part of Phase-II were introduced.

2. Test Facility

The DOBO test facility is designed to simulate the downcomer region below the cold leg in the late reflood phase of the postulated LBLOCA, in which the ECC injection from the SIT is terminated. During this period, most of the parameters in the primary system reaches quasi-steady state, and hence the DOBO facility is designed for a steady-state operation. 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.

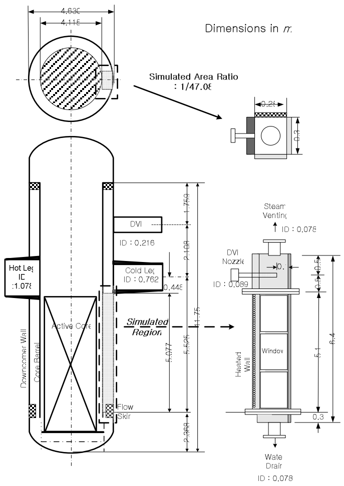

Fig. 1. Geometrical comparison of reactor downcomer of the APR1400 and test section of the DOBO facility

Fig.1 shows the geometrical comparison of the reactor vessel of the APR1400 and test section of the DOBO facility (Details are found in the reference [1]). Several kinds of instrumentations are installed for the measurement of boundary mass and energy flows. Especially, eight DPs are installed for the axial average void fraction distributions. In the Phase-II, local five conductance probes are installed at five elevations along test section for the measurement of bubble parameters. The instrumentation locations for the test sections are shown in Fig.2

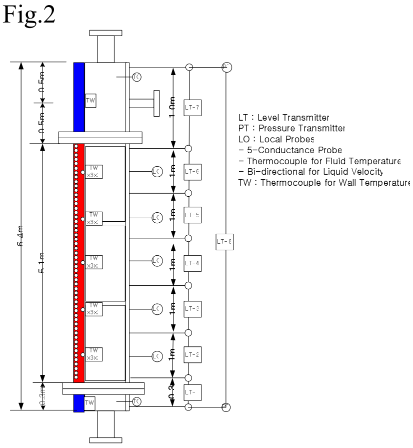

Fig. 2. Schematics of the DOBO Facility

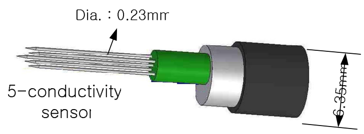

Fig. 3. Local 5 Conductance Probe

Fig.3 shows the schematics of the local five conductance probe. The probe was developed specially for the measurement of three dimensional bubble parameters in the highly swirling flow condition [2].

3. Experiments

A total of five tests including Phase-I and –II were performed in the reflood flow condition, according to the test conditions summarized in Table 1. However, the actual mass flow rate of R1-R4(Phase-I) tests was 10% lower than the ideally scaled one. The R2-1(Phase-II) is a test to measure the local two phase parameters, of which general thermal hydraulic conditions are similar to the R2. The test result showed that the area averaged void fraction calculated from the local void fraction distribution of the R2-1 coincided well with that of the R2 which was obtained from DPs.

Fig. 4 shows the local void fraction and bubble velocity profiles at each elevation of the test section. At the lower part where the boiling is initiated, steam is concentrated near the wall. As goes upward, the void profile becomes wide and a distinct bubbly boundary layer was shown. However, at the two highest regions, center peaking of void profile was found. The void fraction distributions at the lower three elevations show that the local void fraction near the side wall is higher than that of the center line. It is due to the side wall effect. Fig. 4 also shows the bubble velocity distribution and its contour plot. At the highest two elevations, the profile of the bubble velocity is similar to that of the void fraction. In the opposite side of the heated wall, the bubble velocity is very low or negative since the upward bubble motion is suppressed by the downward liquid.

The average interfacial friction coefficient was obtained from the average bubble velocity and water flow rate at inlet. Fig.5 shows the comparison of interfacial friction models adopted in the systems code with the data. The comparison shows that most of the models can not

Table 1 Summary of Experimental Conditions

Parameter	T_{ECC} (°C)	P_{sys} (kPa)	W_{ECC} (kg/s)	Q'' (W/cm^2)
R 1	110.1	162.8	1.22	5.02
R 2	110.2	161.4	1.16	6.97
R 3	109.6	166.5	1.20	8.21
R 4	109.5	170.8	1.20	9.11
R2-1	110.7	158.5	1.33	70.5

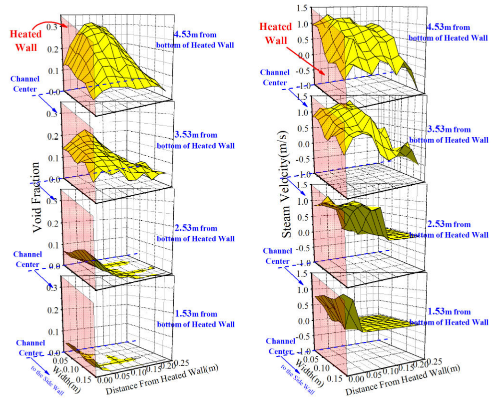

Fig. 4 Propagation of Local Void Fraction and Bubble Velocity(R2-1)

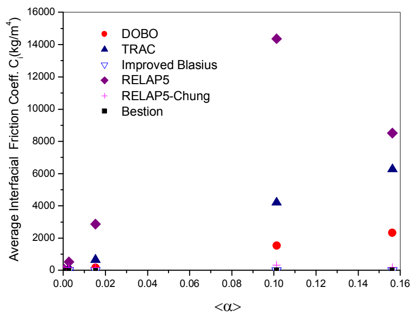

Fig. 5 Evaluation of Interfacial Friction Coeff.

predict present data well and the interfacial friction model should be improved for the better prediction capability of existing system analysis codes.

4. Conclusion

The local bubble parameters were measured in the downcomer boiling condition. The data showed that the interfacial friction model of most of the system codes should be improved.

Acknowledgment

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REFERENCES

[1]B.J.Yun, D.J.Euh and C.-H. Song, "Investigation of the Downcomer Boiling Phenomena During the Reflood Phase of a Postulated Large-Break LOCA in the APR1400," *Nuclear Technology*, accepted in 2006.

[2] D.J.Euh, B.J.Yun, C.-H.Song, "Measurement Method of Interfacial Area Concentration for Highly Fluctuating Bubbly Flow", KNS Autumn meeting, 2005