Proceedings of the Korean Nuclear Society Spring Meeting
Kwangju, Korea, May 2002

TRAC-P Simulation with a 1/7 scaled-down DVI experimental facility

Sang Ik Lee, Hee Cheon NO, Dong Won LEE
Korea Advanced Institute of Science and Technology
Yusong-Gu 373-1, Daejon, Korea
Tel:+82-42-869-3857, Fax:+82-42-869-3895, Email:eruesai@cais.kaist.ac.kr

Han Kon Kim and Seung Jong Oh
Korea Energy Power Research Institute
Munji-Dong, Yusong-Gu 103-16, Daejon, Korea

ABSTRACT

In the present study, several simulations using TRAC-P are carried out with a DVI experiment. The experimental facility is a rectangular channel type scaled down as 1/7 ratio of prototype reactor (APR1400). First, the effect of the nodal size is investigated. Two types of simulation works are performed: air/water simulations and steam/water simulations. In case of air/water simulations, it is possible to apply the fine nodal scheme to describe vessel component. TRAC-P shows a little bit higher bypass fractions in all cases. For steam/water simulations, as the fine nodal scheme causes a numerical convergence problem, a coarse nodal scheme is used in describing the node that connects the DVI water line and the reactor vessel. As a result, while TRAC-P shows discrepancies with the experimental data in bypass fractions, sweep-out water levels and drained liquid temperatures for steam/water simulations, it shows more similar results to them for air/water simulations. These results mainly come from the lack of capability of TRAC-P in prediction of condensation at low-pressure.

I. INTRODUCTION

As one of the advanced design features of Advanced Power Reactor 1400 MW (APR1400) the direct vessel injection (DVI) mode as a safety injection system is adopted instead of a conventional cold leg injection (CLI) mode. Thermal-hydraulic phenomena such as ECC water mixing and its bypass in the downcomer with DVI are expected to be different from those with the existing CLI mode. Especially, when ECC water is injected through DVI in reflood phase, injected ECC water is mixed with the high-speed steam from the intact cold leg and ECC water can be bypassed to the broken cold leg. It is required to confirm the design validity of the DVI mode and to enhance understanding on thermal-hydraulic phenomena in the downcomer.

Validation of best-estimated codes are required for their applicability to the Large Break Loss Of Coolant Accident (LB-LOCA) situation of APR-1400. Related with these, several experimental works are performed at Korea Advanced Institute of Science and Technology (KAIST) with a 1/7 scale-down facility and simulation results by TRAC-P of this facility are compared with experimental results.

II. DESCRIPTION OF EXPERIMENTAL WORK

Several experiments related to the thermal-hydraulic phenomena in the downcomer with DVI under LBLOCA were carried out using the experimental facility of plane channel type which was scaled down as 1/7 ratio of prototype reactor (APR1400)[4],[7]. Especially, the phenomena such as ECC water entrainment and mixing in downcomer were focused in the experimental work. Test section was made in the form of a plane-channel scaled down linearly as 1/7 ratio of prototype reactor (APR1400) as shown in figure 1. As a result of scaling, the diameters of DVI and cold leg were 0.03 m and 0.109 m, respectively. This facility was designed and manufactured as shown in figure 2 to supply the air/steam and water and to measure information such as temperature, pressure, flow etc.

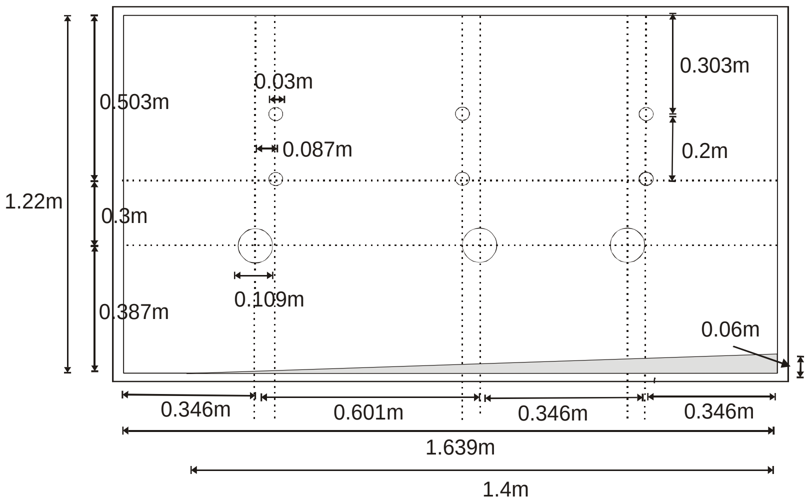

Figure 1 The rectangular channel used in the experiment

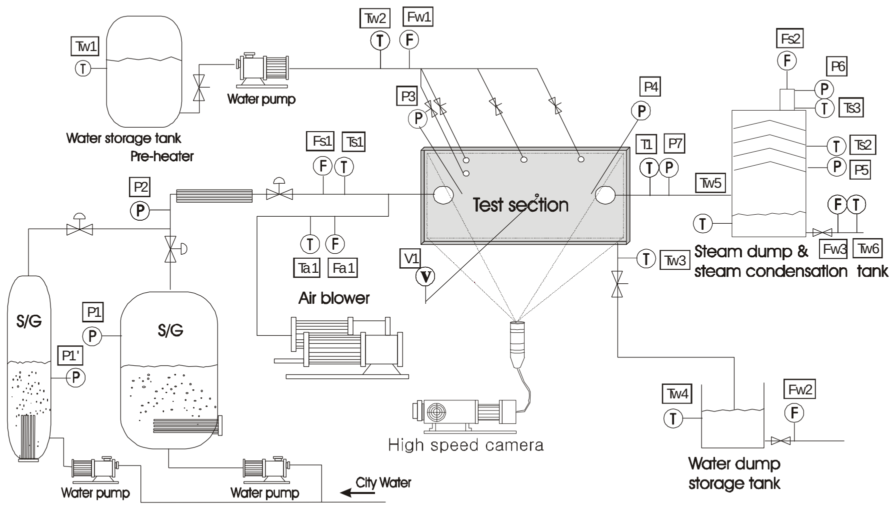

Figure 2 System diagram of the DVI experimental facility

III. DEVELOPING PROCEDURE

To constitute an input deck for steam/water mixing experiments in the downcomer with DVI, simulation requirements and its simplifications were investigated as shown in figure 3. To simulate the rectangular-channel type test section, a part of a 3-D VESSEL component was used as shown in Figure 4, which shows the partition of the VESSEL component. Especially, the dark area indicates the rectangular-channel type test section of the DVI experimental facility. To mitigate the curvature effect of the 3-D VESSEL, a small partition of the 3-D VESSEL component as 1/24 of a whole circle in the top view of a cylinder was used in the calculation. And then, this partition was nodalized again to locate the cold legs and DVI lines. Several simulations were performed to see the effect of the nodal scheme. These simulations were performed from the coarse nodalization of this rectangular type channel to fine nodalizaiton with consideration of position of cold-legs, and DVI lines [4].

Simulation results showed an oscillation in void fraction for cases with the coarse nodal scheme. To mitigate the interference effect of this neighbor cell, a fine nodal scheme is used as shown in figure 5. The lowermost and uppermost cells in the axial direction are fictitious cells to designate the downcomer region in the 3-D VESSEL component of TRAC-P [6]. This nodal scheme is directly used in describing the air/water mixture experiment. But, in description of the steam/water mixture experiment, the thermal-hydraulic transient is quite more severe than the air/water case. Therefore, a slightly different node scheme is used in simulations of steam/water. The main difference is the size of cells connected with DVI lines. Figure 6 shows the node scheme used in the simulation of the steam/water mixture experiment.

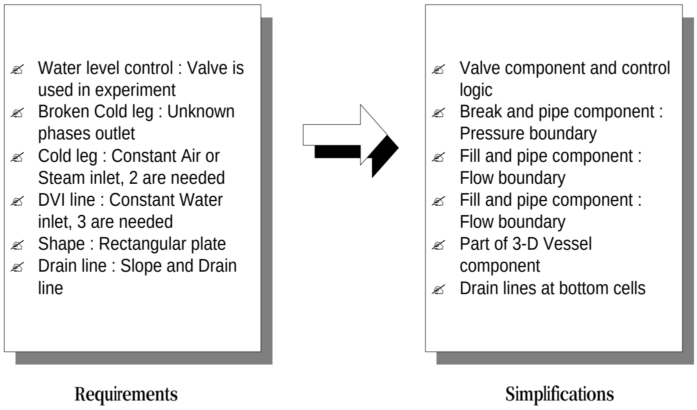

Figure 3 Requirements and simplification of simulation for the DVI experimental facility

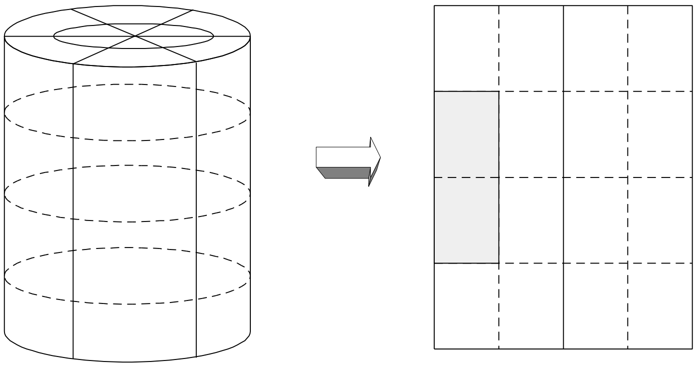

Figure 4 Method of description of downcomer

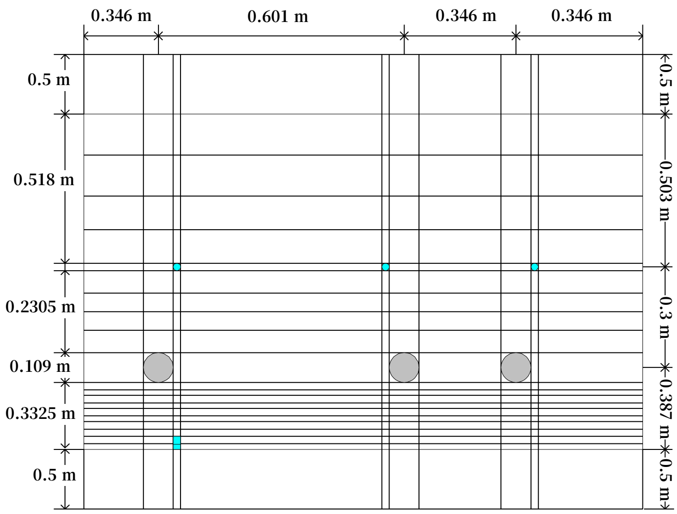

Figure 5 Nodalization used for air/water mixture simulations

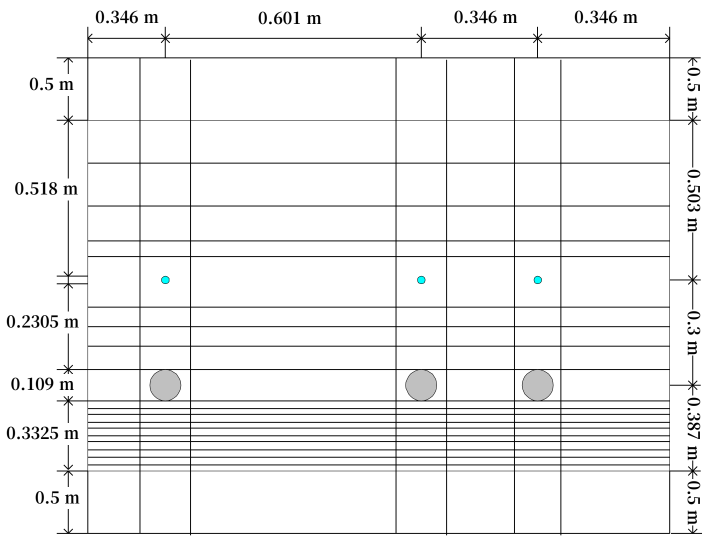

Figure 6 Nodalization used for steam/water mixture simulations

IV. SIMULATION RESULTS

4.1 Air/water mixing simulation

In simulation works of the air/water mixing experiment, the node scheme shown in figure 5 is used. The liquid level in the downcomer is selected as a control variable and is held constant by using control logic during simulation. A 60-second transient calculation is performed using TRAC-P. Drain lines are connected to the lower bottom of the downcomer. Drained water passes through these lines to make the water level constant. The water mass flow rate through the drain line is controlled by a valve component. Air comes in from two intact cold legs that are located on the right side of the downcomer. Air and entrained water flows out through the broken cold leg that is located on the leftmost side of the downcomer. Liquid level is controlled at a constant value of 16cm. Bypass fraction is calculated from the following equation:

$$Bypass\quad fraction = \frac{W_{ECC,out}}{W_{ECC,in}} \tag{1}$$

Several tests are performed with varying water and air mass flow rates. These results are summarized in table 1. All cases of table 1 are analyzed and presented in the simulation result section. ECC water flow rates at the broken cold leg and liquid level in the downcomer with the same injection ECC water flow rate are presented in (1), (2) and (3).

The bypassed ECC water mass flow rate decreases with increasing air mass flow rate.

In view of liquid level results, the level is well controlled at a value of 16cm.

Table 1 Bypass fraction in the simulation results of air/water experiment

Water \ Air	0.1(Kg/s)	0.15(Kg/s)	0.22(Kg/s)
0.52(Kg/s)	11.6 %	10.2 %	10.5 %
1.06(Kg/s)	10.9 %	9.00 %	8.67 %
1.712(Kg/s)	10.8 %	8.90 %	7.64 %

Air/water mixture simulation results

(1) Simulation results for $W_{ECC,in}$ = 0.52 kg/sec

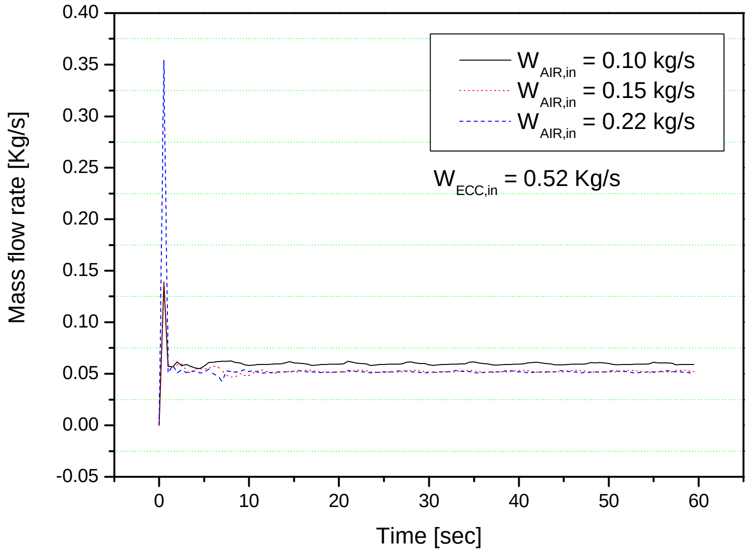

Figure 7 Bypassed water mass flow rate with varying air mass flow

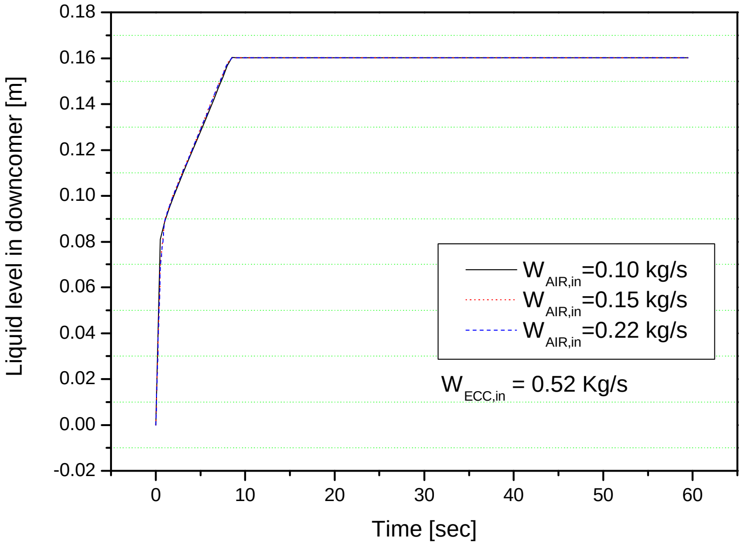

Figure 8 The downcomer liquid level with varying air mass flow

(2) Simulation results for $W_{ECC,in}$ = 1.06 kg/sec

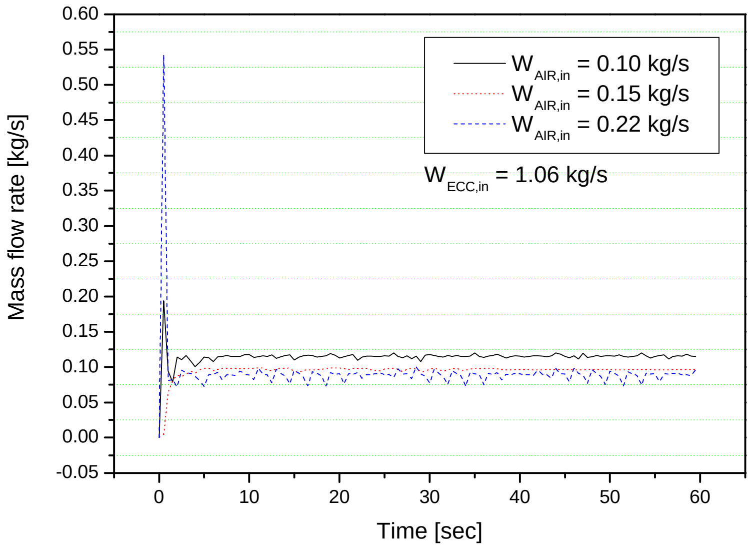

Figure 9 Bypassed water mass flow rate with varying air mass flow

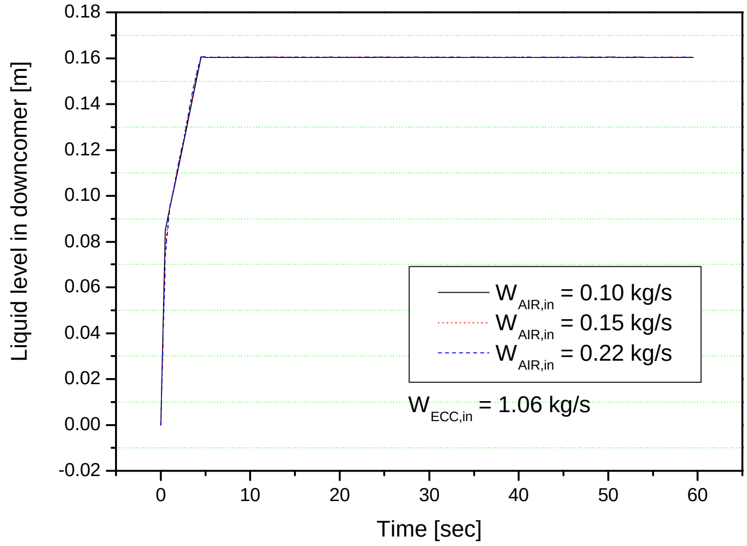

Figure 10 The downcomer liquid level with varying air mass flow

(3) Simulation results for $W_{ECC,in}$ = 1.712 kg/sec

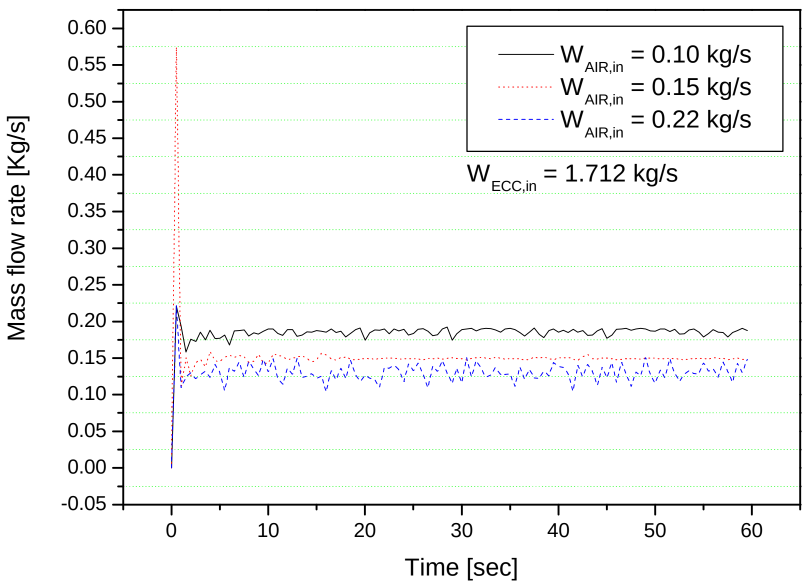

Figure 11 Bypassed water mass flow rate with varying air mass flow

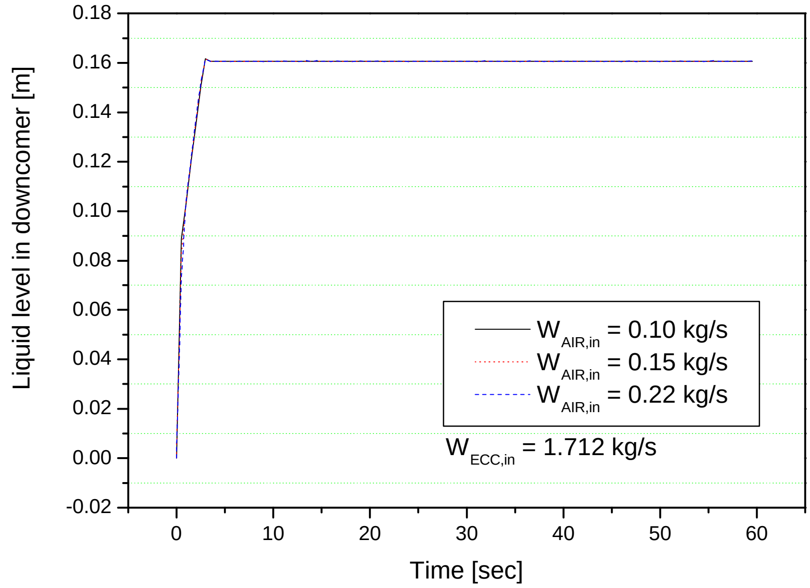

Figure 12 The downcomer liquid level with varying air mass flow

4.2 Steam/water mixing simulation

Simulations of steam/water mixture experiments are different from those of air/water mixture because of the condensation between phases. Condensation in the downcomer causes depressurization in the system. In these situations, the initial transient can not converge to steady state. Therefore, a different node scheme is used in the simulation of the steam/water mixture experiment as shown in figure 6. The condensation transient might be the severest in cells connected to the DVI lines and TRAC-P is more likely to diverge for a finer node scheme. Therefore, the larger cell size of a DVI-connected cell is suggested and used in the calculation. In the process of 1/7 scale-down ratio, the position of the DVI line is slightly different from the cold leg position in the horizontal direction, but consideration about this effect can not be applied for steam/water mixture simulations. The bypass fraction is calculated using equation (1). The calculated bypass fraction might be higher than that of the experimental one because there is no consideration of the amount of steam condensation. But there was a negligible effect of the amount of condensed steam on bypass fraction in the experiment. This effect is neglected in these simulations for the accordance with experimental results. The simulation results of steam/water mixture experiments are summarized as shown in table 2. The steam velocity is about twice that of air velocity at the same gas mass flow rate. As a result, the liquid level is controlled at 5 cm rather than 16 cm to avoid sweep out.

Bypassed ECC water mass flow rates in figure 13 show severe transient during the simulation time. Only for case ② and ④ in table 2, is it possible to say that the initial transient converged to steady state. The bypassed ECC water mass flow rate is nearly zero for these two cases. For case ① and ③, the initial transient continues during the entire simulation time: calculated bypass fraction values have no meaning with these two cases.

Simulation results of liquid level variations in figure 14 show that they were not controlled at a constant value during simulation. These liquid level variations are thought to be affected by condensations and temperature differences because those liquid level variations did not occur at air/water simulations. Simulations that do not continue for 60 seconds in table 2 may be caused by these transient.

Liquid temperature at the drain line in figure 15 is important because sufficient subcooling margin is required to cool down the overheated reactor core. The simulation results show that water temperature going out through drain line is 373K, which does not support sufficient subcooling margin.

Table 2 Bypass fraction in the simulation of steam/water experiment

Water \ Steam	0.1	0.15	0.22
0.62	①8.76 %	-	- *
1.06	②0.00 %†	-	③19.66 %
1.712	-	-	④0.12 %

* The (-) sign in table 2, means the simulation does not continue for 60 sec. and the result has no meaning.

† The shaded area in table 2, means the simulation result that converges to steady state.

Steam/water mixture simulation results

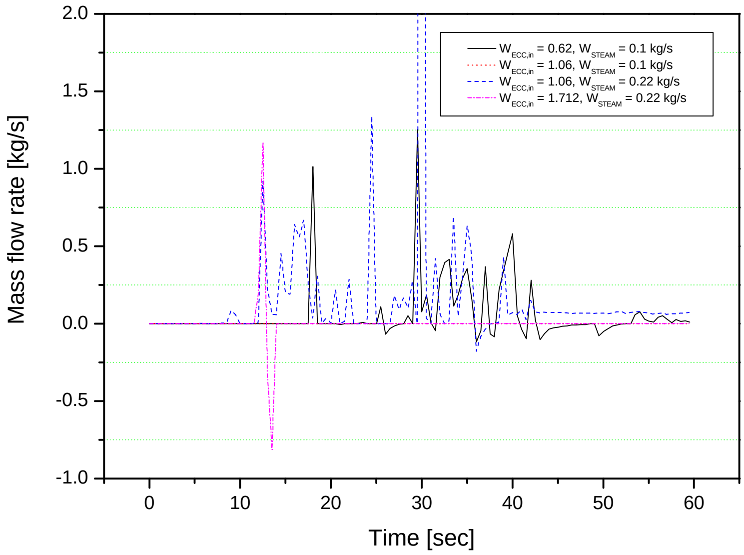

Figure 13 ECC water mass flow rate at the broken cold leg

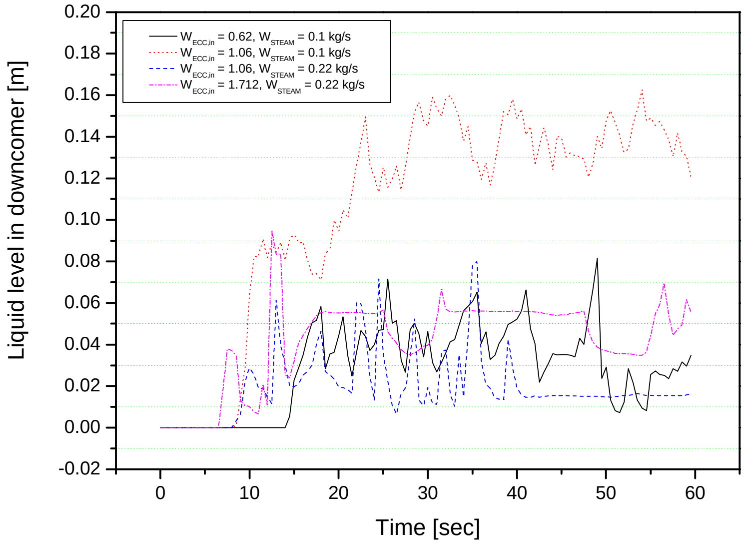

Figure 14 Liquid level in downcomer

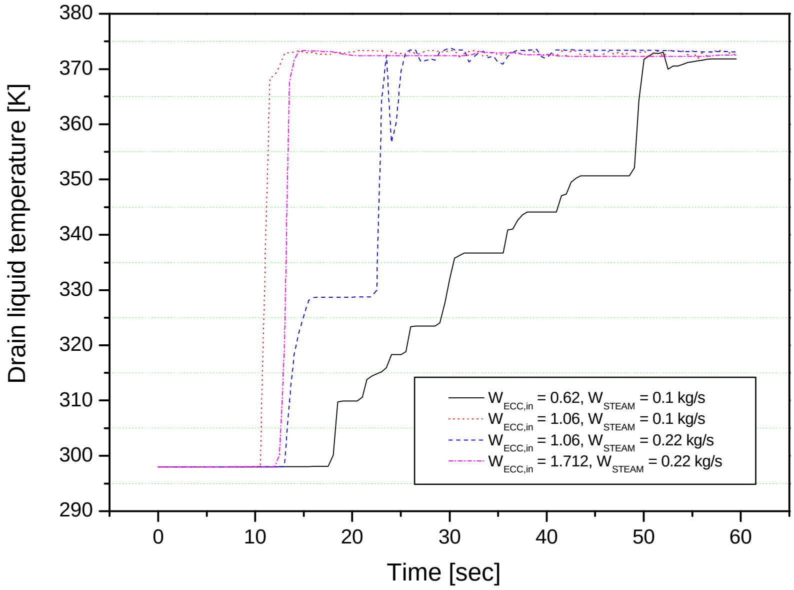

Figure 15 Liquid temperature in the drain line

4.3 Comparison with experimental results

Figures 16 and 17 show the comparison between simulation results and experiments. For air/water mixture cases, calculated bypass fractions are about twice those of experimental results in all air/water cases. From these results, we can say that the interfacial force in the TRAC-P code, which carry ECC water through broken cold leg, is higher than the real one. In figure 16, the bypassed water mass flow rate decreases with increasing air injection flow rate in contrast with the experimental result. The reason for this aspect is not clear.

For steam/water cases, shown in figure 17, calculated bypass fractions agree well with experiments for two cases while the other two cases do not. TRAC-P estimates higher heat transfer and higher interfacial force than experimental results do.

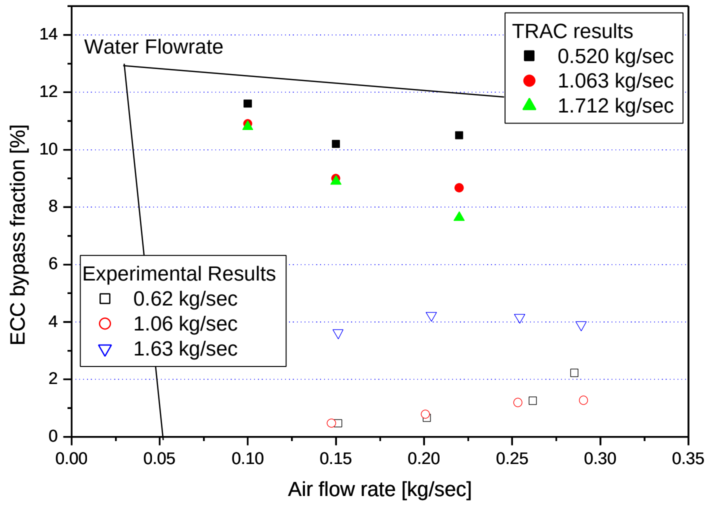

Figure 16 Comparison of bypass fraction between numerical and experimental results for air/water mixture

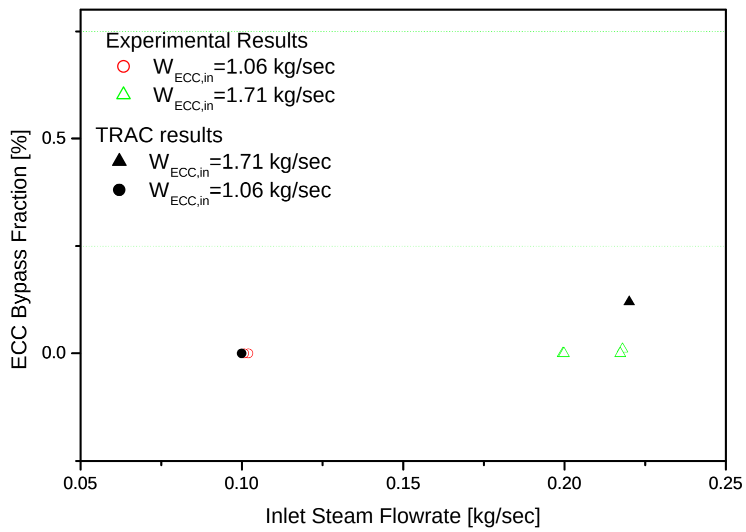

Figure 17 Comparison of bypass fraction between numerical and experimental results for steam/water mixture

V. CONCLUSIONS

For air/water mixture simulations, bypass fraction is about two time higher than experimental results. This result seems to be the effect of interfacial friction between phases in TRAC-P code being higher than real situations.

For steam/water simulations, bypass fraction shows good agreement with experimental result, only for ② and ④ in table 2, but the main reason for these agreements is that there is no interfacial force to carry out the liquid droplet or liquid film due to high condensation.

Large oscillation with a fine nodal scheme occurs during the simulation of steam/water case: in this case we need more coarse nodal scheme.

The correlations used in TRAC-P in the interfacial heat transfer were compared with experiments with the simple rectangular channel geometry facility and with this 1/7 scaled-down geometry. Interfacial heat transfer coefficients calculated by TRAC-P code is somewhat larger than those of experiments[4].

This excessive condensation causes the steam flow rate vented to the broken cold leg to be nearly zero, or in some cases, negative. And these effects might make convergence with the TRAC-P code difficult. Therefore, there may occur a necessity of modification of TRAC-P code in the estimation of the interfacial heat transfer coefficient.

ACKNOWLEDGEMENT

This work has been supported by Korea Electric Power Research Institute (KEPRI) through research contract. Special thanks are given to Dr. S. J. Oh, and Dr. H. G. Kim.

NOMENCLATURE

$W_{ECC,in}$: ECC water mass flow rate (kg/s) that comes into the rectangular channel

$W_{ECC,out}$: ECC water mass flow rate (kg/s) that spills out from the rectangular channel through broken cold leg

W_{AIR} : Air mass flow rate (kg/s) that comes into the rectangular channel

W_{STEAM} : Steam mass flow rate (kg/s) that comes into the rectangular channel

REFERENCES

[1] Development of Three-dimensional Thermal-Hydraulic Safety Analysis Technology for Direct Vessel Injection, KINS/RR-009, Feb 2000.

[2] S. H. Chang and W. P. Baek, Nuclear Safety, Chung Muk Kak press.

[3] Kyoo Hwan Bae, et al., Design options for the safety injection system of Korean next generation reactor, Annals of nuclear energy 27 (2000), pp1011-1028.

[4] KEPRI, A Study of the Mixing Phenomena of Subcooled Water with Superheated Steam, TR.99NJ13.J2001.614 (2001)

[5] TRAC-PF1/MOD2 Code Manual, NUREG/CR-5673, July 1997.

[6] TRAC-P User’s guide, NUREG/CR-5673V2, July 1992.

[7] Dong Won LEE, et al., ECC water film spreading ECC water Bypass and Sweep-out Phenomena in th Downcomer with DVI of APR1400 under LBLOCA, ANS 2002 Annual Meeting (prepare to press)