Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Experimental Study of PWR Coolant Mixing Phenomena Using Wire-Mesh Sensor

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1. Introduction

Mixing phenomena of coolant with different boron concentration in the primary system of pressurized water reactor (PWR) plays an important role during normal operation and accident conditions because of the reactivity [1, 2]. In the case of emergency core cooling (ECC), the mixing phenomena in the lower plenum can be used to evaluate the performance of ECC injection. This paper presents the experimental results of mixing phenomena related to cold leg injection (CLI) during a postulated accident in PWR. In these tests, test conditions were not appropriate for the simulation of the real reactor situation because the main purpose of the present study was to evaluate the mixing phenomena of the CLI mode. Additional test for direct vessel injection (DVI) is planned as a future work, although not shown here.

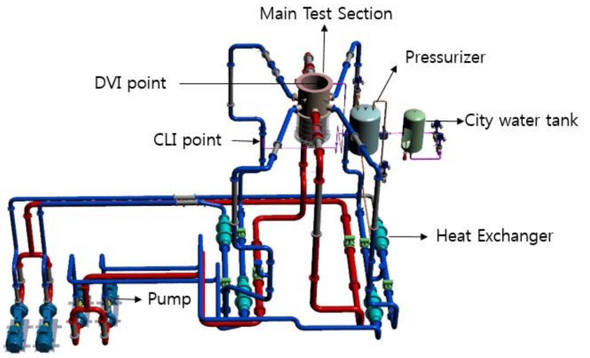


Fig. 1. Schematic of the 1/5-Scale Mixing Test Facility

2. Experimental Test facility

The 1/5-Scale mixing test facility was construed with a 1/5 linear scaling ratio to simulate fluid flow phenomena inside the reactor vessel of Korea's PWR. All internal structures were exactly simulated according to the principle of similarity. The schematic of the test facility and the main test section are shown in Figs 1 and 2, respectively. The system was constructed as a close loop to recirculate the coolant. The test facility was designed to evaluate mixing of ECC water injected into the cold leg or DVI nozzle of PWR. Specialized wire-mesh sensors which is a well-known high-resolution instrumentation in time were set up at the core inlet and downcomer region without hindering the flow path. Total number of wire-mesh sensors in the downcomer region is 16, and each sensor has 4 measuring points. In the core region, 17×17 measuring points were arranged along the location of fuel assemblies, as shown in Fig. 3.

The test facility is basically operated with de-mineralized water, but the loop conductivity can be adjusted to meet the test requirements by using a salted water in injection water tank. The ECC water injection is controlled by using automatic control valves, and there are two injection points to cover the ECC injection scenario, as shown in Fig. 1.

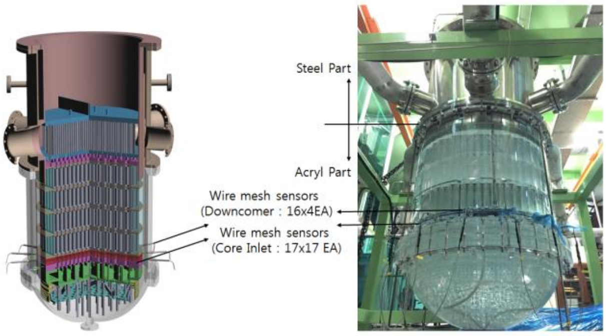


Fig. 2. Main test section of test facility

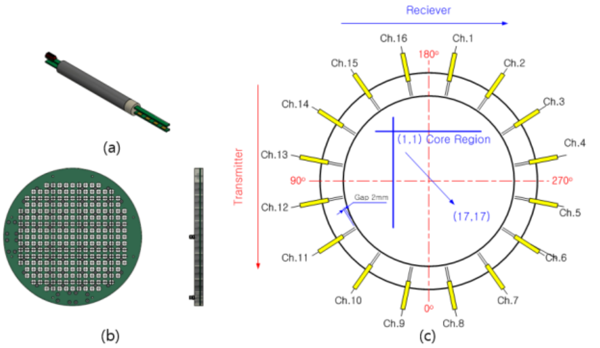


Fig. 3. Wire-mesh sensors layout (a: 1×4 sensor. b: 17×17, c: location of W/M)

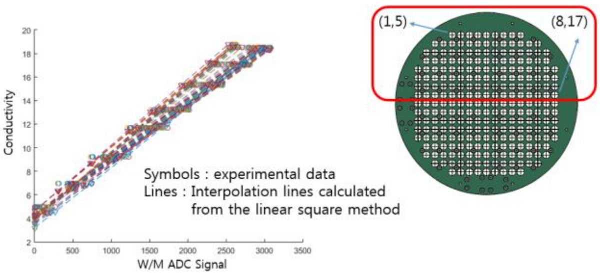
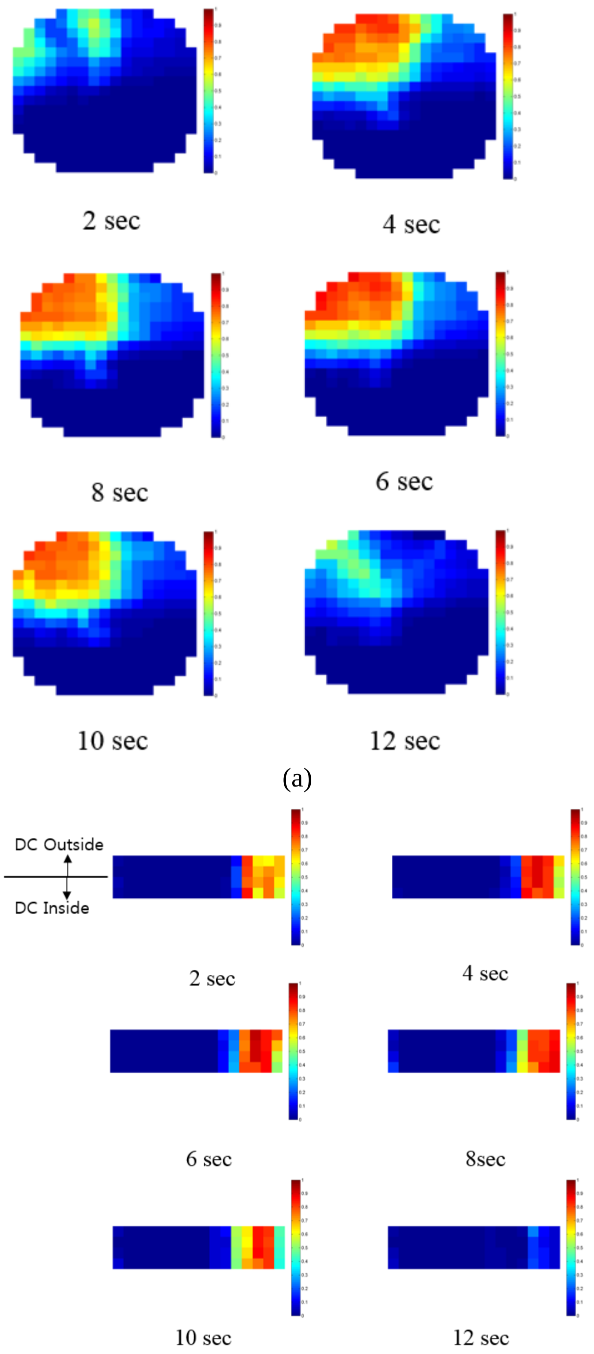


Fig. 4. Calibration test results for the core inlet points

3. Test results and discussion

The system pressure and temperature were maintained at the atmosphere pressure and room temperature, respectively. The wire-mesh sensors highly depends on the temperature and conductivity. Thus, all measurement points were calibrated by increasing loop conductivity. Figure 4 shows an example of the calibration results at several measurement points. In the present test, the temperature effect on the measurement was not considered since the ECC water temperature was same as the loop temperature during experiment.



(b)

Fig. 5 Instantaneous contour map of coolant mixing scalar (a: core inlet region, b: downcomer region)

Test facility was operated until the loop conductivity, temperature and pressure reach a quasi-state state. After that, the high conductivity ECC water adjusted by using salt was injected during 10 sec into the cold leg. Conductivity sensors were set up at 6 positions in the loop. The measured signal of wire-mesh sensors were converted into a dimensionless parameter scalar as follows;

$$\theta_{i,j,k} = \frac{\sigma_{m\,i,j,k} - \sigma_{0\,i,j,k}}{\sigma_{inj\,i,j,k} - \sigma_{0\,i,j,k}} \qquad (1)$$

where, $\sigma_{inj\,i,j,k}$, $\sigma_{o\,i,j,k}$ and $\sigma_{m\,i,j,k}$ shows the measured conductivity of ECC water in the cold leg, measured reference loop conductivity and measured conductivity of wire-mesh sensors, respectively. The k is a time marching index. Thus, Θ represents the relative magnitude between the injection point and measurement point in time and space.

The contour map of Θ are shown in Fig 5. At t= -5 sec, the ECC water was injected into the cold leg. The maximum values of the mixing scalar was 87.7% and 91.4% in the core region and downcomer region, respectively. The difference is caused by the coolant mixing between the ECC water and the diluted loop coolant passing through the lower plenum. In this study, the mixing phenomena was quantified and visualized well with high resolution in space and time.

4. Conclusion

Experimental study for the transient mixing phenomena of the ECC water has been carryout out with the CLI mode. The tests were performed in the 1/5 scale ECC bypass test facility, and a specialized wire-mesh sensors were used in the core inlet and downcomer region. All measured signals were converted into a dimensionless mixing scalar calculated from the measured values of conductivity. In the present study, the mixing phenomena at the core inlet and downcomer region was quantified well along the time sequences and the location of fuel assemblies with high resolution in time and space. It is expected that these results can be used for the validation of safety analysis or CFD codes.

Acknowledgments

This research has been performed as a part of the nuclear R&D program supported by the Ministry of Trade, Industry & Energy of the Korean government.

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