Simulation of Boron Dilution Benchmark using CUPID Code

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1. Introduction

USNRC reported that de-borated water or low boron concentration water, which is accumulated in the RCP suction piping, can flow into the reactor pressure vessel (RPV) when the reactor coolant pump (RCP) startup after the recovery of the small break loss of coolant accident (SBLOCA). In addition, inadvertent boron dilution happens as a result of human error. Thus, the unexpected reactivity insertion can occur if the low boron concentration water flows into the core inlet without enough mixing in the downcomer and lower plenum regions. Therefore, it is important to predict the boron mixing phenomenon by the turbulence effect as well as the convection and diffusion. Recently, IAEA launched a coordinate research project (CRP), 'Application of computational fluid dynamics code for nuclear power plant design', to validate the capability of CFD codes for simulations of nuclear safety-related issues. In the IAEA CRP, ROCOM_12 test was selected as a numerical benchmark exercise to validate the CFD code capability to predict the boron mixing phenomenon [1].

2. Simulation of ROCOM Test

2.1 ROCOM_12 Test [2]

ROCOM is a 1:5 model of a PWR of GERMAN KONVOI type that consists of 4 loops. The inner diameter and height of RPV are 1,000 mm and 2,400 mm, respectively. The wire mesh sensors were installed to measure the flow distribution in the cold leg inlet nozzle, core inlet plane, and downcomer. Each sensor has two-dimensional grids that consist of the measuring points of 216, 15x15, and 29x64, respectively.

The slug mixing experiment ROCOM_12 was performed with simulating the slug volume of de-borated water. The initial and boundary condition of ROCOM_12 is summarized in Table 1.

Table I: Initial and boundary condition of ROCOM_12

Ramp length	Volume flow rate	Slug volume	Initial slug position
14 s	185.0 m^3/h	8.0 m^3	10.0 m

2.2 Computational Grid and Models

CUPID code was used for ROCOM_12 simulation. CUPID is capable of boron mixing simulation in the ROCOM because it has relevant physical models such as the boron transport model, standard k-e turbulence model, and low Reynold number turbulence model. Both hexagonal and tetrahedral meshes were generated by using SALOME software. The geometry of ROCOM was divided into four parts: 1) the cold legs and downcomer, 2) lower plenum, 3) tubes, and 4) upper plenum and hot legs. The grid for each part was generated and then compound grid was generated as shown in Figure. 1. Total number of grid was 4,679,887.

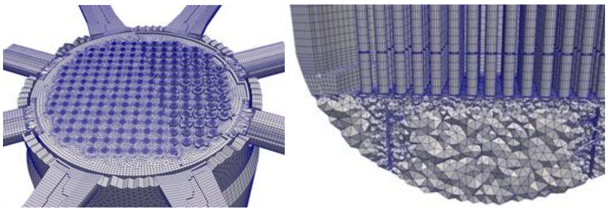

Fig. 1 Grid generation for ROCOM simulation

3. CUPID Calculation Results

3.1 Space-averaged Boron Concentration

Boron concentrations at three measuring planes were simulated: upper downcommer, lower downcomer and core inlet. Figure 2 and Figure 3 show the maximum and averaged boron concentration at each measuring plane, respectively. The averaged boron concentrations were underestimated while the maximum values agreed well. It is responsible for the bypass of boron through three open cold legs and this bypass effect was not quantitatively validated since the boron bypass rate was not measured.

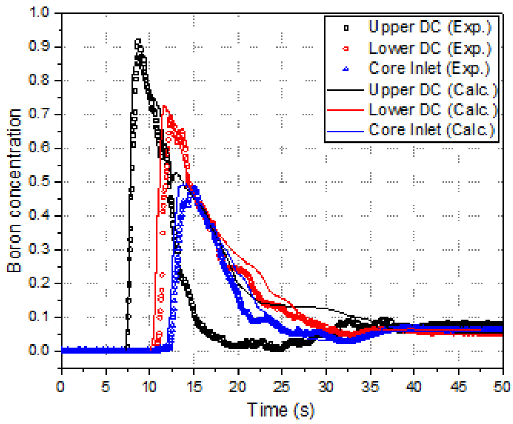

Fig. 2 Maximum boron concentration at three planes

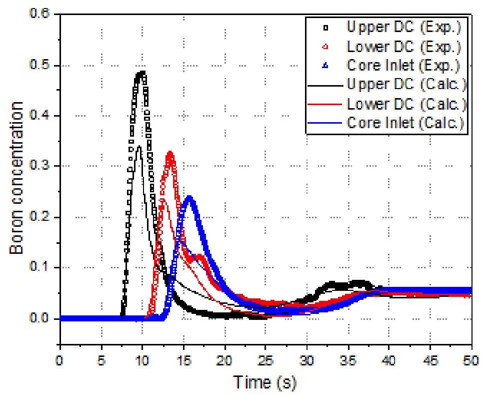

Fig. 3 Averaged boron concentration at three planes

3.2 Transient Local Boron Concentration

Local boron concentrations at five measuring points were simulated as shown in Fig. 4. Two points were located at the upper and lower downcomer, and other three points were assigned at the core inlet.

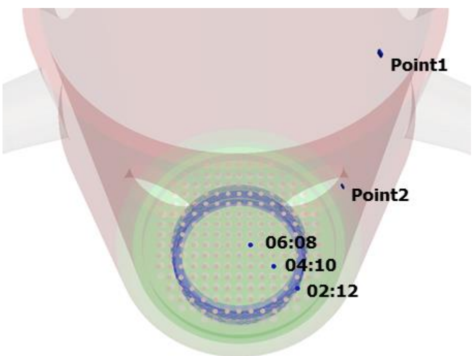

Fig. 4 Local measuring points

Fig. 5 shows the transient behavior of boron concentration at two local points in the upper (point1) and lower downcomer (point2). The transient trend of boron concentration at point1 was predicted well. However, the timing of the first peak of boron concentration at point2 was predicted faster than the experimental data. This result implies that the borated water flowed downward faster without enough flow mixing.

Fig. 6 shows the transient behavior of boron concentration at three local points in the core inlet. Experimental data showed that the boron filled from the outer radial point of the core inlet and then, inner radial point and middle radial point in order. However, the simulation result showed that the boron filled from the outer radial point and then, middle radial point and inner radial in order. This discrepancy is also responsible for the flow mixing phenomenon in the core inlet as well as the downcomer region. Thus, it is required to perform a sensitivity test with varying turbulence model and a grid resolution near wall.

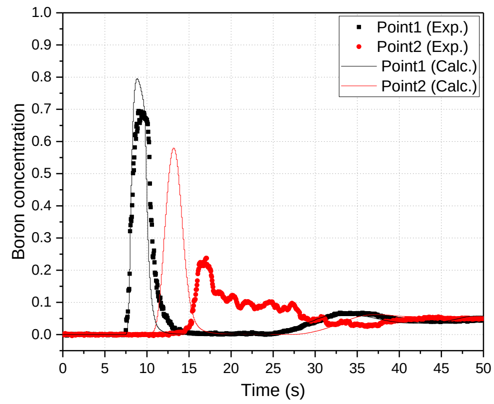

Fig. 5 Local boron concentrations at two points in uper and lower downcomer

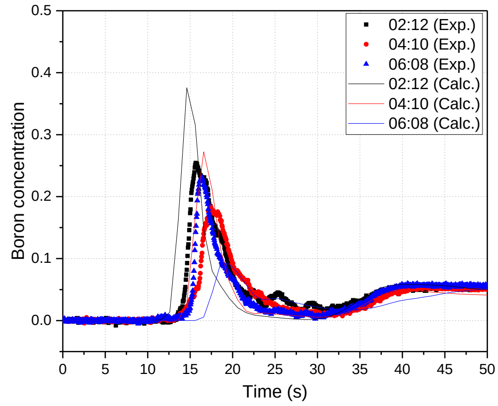

Fig. 6 Local boron concentrations at three points in core inlet

5. Conclusions

Test ROCOM_12 test was simulated using the CUPID code. It was shown that CUPID had capabilities to properly simulate the boron mixing behavior which is injected asymmetrically. Overall boron concentrations were predicted well while the transient behavior of local boron concentrations showed somewhat discrepancy. The further works may involve a sensitivity test on the turbulence model and local grid resolution.

ACKNOWLEDGMENTS

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