Validation of the Condensation Model in the CAP Code with the BFMC-D1 and D12 Tests

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1. Introduction

In Korea, new efforts to develop the nuclear safety codes for the accident analysis are actively undertaken to improve the safety analysis capability. As a part of the efforts, CAP (Containment Analysis Package), a computational code for the containment analysis, is under development by the Future and Challenge Company since 2010 [1]. The CAP code enables to calculate thermal-hydraulic behavior in the containment in two-dimension and employs the lumped parameter model to evaluate the integrity of containment, the performance of emergency core cooling system and qualification of equipment.

In the CAP code development process, it is of essence that verification and validation (V&V) of the code should be conducted. For the V&V efforts, a total of 6 tests including 4 SETs (Separate Effect Test) and 2 IETs (Integral Effect Test) were selected for the independent evaluation. Among them, the V&V results for two tests, D1 and D12, performed in the BFMC (Battelle-Frankfurt Model Containment) facility [2] will be presented in this article.

2. The BFMC Facility and Tests

BFMC is a containment test facility as shown in Figure 1 to study the thermal-hydraulic response of a containment system during accident conditions and to use test data to assist development of related thermal-hydraulic codes named GOTHIC. BFMC is a multi-room facility and it can arrange various room configurations by concrete inserts.

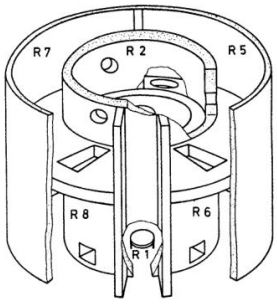

Fig. 1. Cutaway View of Interior Rooms in BFMC

2.1 SET1 - Steam Blowdown (BFMC D1 TEST)

The BFMC D1 test is a steam blowdown experiment following a steam line break. The primary interest of the test is the time period immediately after the break when the differential pressures between rooms are highest. These differential pressures apply forces on the walls of a containment which can cause a structural failure.

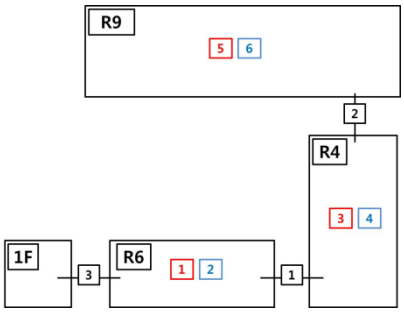

Fig. 2. Schematic Model in the BFMC D1 Test

In the test, three rooms were connected, R6, R4 and R9 for the rest of rooms. The blowdown steam flows into R6, passing through R4 and reaches to R9. Initially, temperatures were between 10 and 15 ℃ and pressure was 1 atm in the containment. Also, pressure and temperature of the blowdown steam were 70 bar and 285 ℃, respectively. Total time of the test was 3.0 sec. The D1 test only concerns a few seconds since the peak of differential pressure was attained within seconds or even fractions of a second. Figure 2 shows a schematic diagram for the GOTHIC simulation. And Figure 3 shows a break steam flow rate into R6. For the CAP simulation, the same condition and configuration were employed.

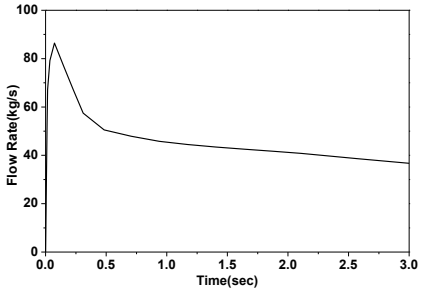

Fig. 3. The Blowdown Steam Flow Rate in the BFMC D1 Test

2.2 SET2 - Hydrogen Convection and Diffusion (BFMC D12 TEST)

When LOCA occurs, hydrogen gas might be generated from chemical reaction between fuel and cladding and can form high concentration of hydrogen leading an explosion. The BFMC D12 test is designed to study transport of hydrogen by convection and diffusion in that kind of accident situation. This test was

conducted under isothermal conditions with sufficiently low feed flow rate of hydrogen and nitrogen mixture.

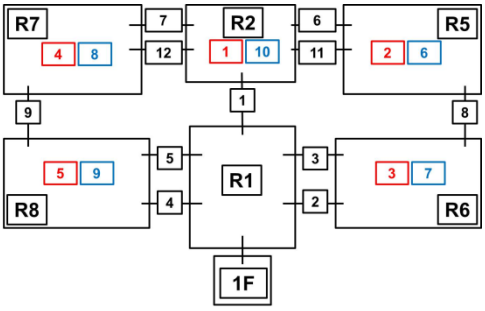

Fig. 4. Schematic Model in the BFMC D12 Test

In this test, six rooms were used, R1, R2, R5, R6, R7 and R8. Gas is injected into R1 and goes to other rooms and they will have certain stable hydrogen ratio at the end stage. The initial temperature and pressure were 16 ℃ and 1 atm, respectively, in the containment. Injected gas temperature was 14 ℃ and consisted of 67 % hydrogen and 33 % nitrogen by volume. Since CAP has no equation of states for nitrogen, however, air is used for nitrogen in the gas. Figure 4 shows a schematic diagram of the GOTHIC simulation and CAP. Figure 5 shows a flow rate of the gas mixture into R1.

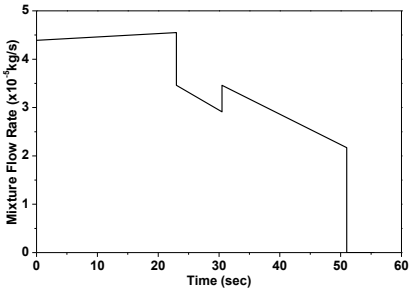

Fig. 5. Flow Rate in the BFMC D-12 Test

3. Code Verification and Comparison Results

3.1 SET1 - Steam Blowdown (BFMC D1 TEST)

Since the Diffusion Layer Model (DLM) [3] was used in the GOTHIC code for a condensation model but not in the CAP, the Uchida correlation [4] for the condensation model was used for this V&V. It was noted that GOTHIC with the present test conditions predicted no significant difference in results between DLM and the Uchida correlation.

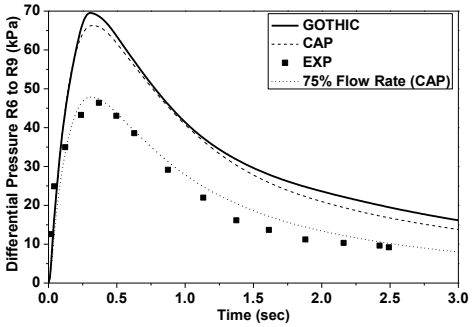

Fig. 6. Differential Pressure R6 to R9

In general, both GOTHIC and CAP results (Figure 6 shows the differential pressure between rooms) show nearly identical behaviors in pressure but over-estimates approximately 25% to the experimental data. It was noted in the reference [2] that the experimental data might have some uncertainty and suggested to use the reduced steam flow rate, e.g., 80%. The CAP analysis with the 75% steam flow rate matches well with the experimental data.

3.2 SET2 - Hydrogen Convection and Diffusion (BFMC D12 TEST)

Figure 7 shows hydrogen pressure ratio in each room of the BFMC D12 test. Both GOTHIC and CAP results show good agreement in the prediction of hydrogen pressures. However there is a marginal difference between the calculation and experiment as time increases.

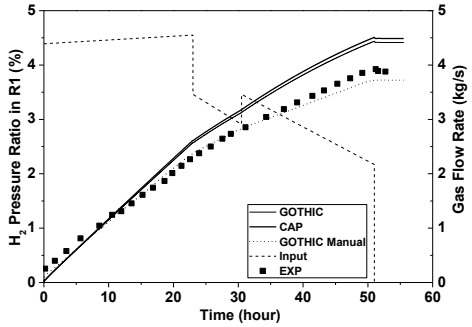

Fig. 7. Hydrogen Pressure Ratio in R1

4. Conclusion

Two experiments at the BFMC facility were evaluated with CAP and GOTHIC for the V&V of CAP. In general, CAP agrees well with the GOTHIC predictions and the BFMC test results with the consideration of experimental uncertainty for both the blowdown and hydrogen dispersion phenomena with GOTHIC. The V&V efforts showed that the CAP condensation model had good evaluation performance for the containment analysis. The V&V study will continue for the PANDA Phase A test and MARVIKEN test.

ACKNOWLEDEGEMENTS

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