Results of OECD-NEA THAI Test HM-2 Benchmark Study with MELCOR Code

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1. Introduction

OECD-NEA performed THAI (Thermal hydraulics, Hydrogen, Aerosol and Iodine) Project from 2007 for three years to address open questions concerning the behavior of hydrogen, iodine and aerosols in the containment of water cooled reactors during severe accidents. In the project nine OECD member countries joined including seven European countries, Canada and Korea. In Korea, KAERI and KINS participated in the project. There was a benchmark study concerning hydrogen mixing phenomena occurred in HM-2 test and KINS took part in the benchmark program to assess MELCOR code characteristics and capabilities for the relevant phenomena.

This paper summarizes major results obtained from the benchmark program. In HM-2 test, hydrogen was injected into the THAI test vessel for 4,200sec (phase 1) and an atmospheric stratification occurred. After 2 minutes, Steam was released at the nozzle located at the central region of the lower plenum from 4,320sec to 6,820sec (phase 2). In phase 2, a stagnation of steam plume in the inner cylinder occurred and the stratified hydrogen region was eroded by the plume and finally a global natural circulation flow was formed to mix overall atmosphere in the vessel.

2. Results of Simulation with HM-2 Test

The benchmark study has been performed with two steps; the blind calculation and the open calculation. For blind calculation the Project released data only for phase 1. In open calculation, all data of both phase 1 and 2 was opened to the participants for tuning their own inputs or models. In the blind calculation we used 67-CV (control volume) model of 9 vertical levels in MELCOR analysis, while a much more detailed model of 174 CVs with 22-level was used the open calculation.

2.1 Phase 1 – Hydrogen Injection and Stratification

Figs. 1 and 2 show pressure buildup in test vessel and hydrogen distribution resulted from open calculation. As also indicated in the blind calculation results, MELCOR simulations of both blind and open calculations resulted in the overestimation of the mixing of atmosphere, compared to the experiment [1]. The highest hydrogen concentration in predictions was about 30% at the end of phase 1 while about 37% in the experiment. There was no considerable improvement in the open calculation simulating the atmospheric stratification with detailed vertical discretization.

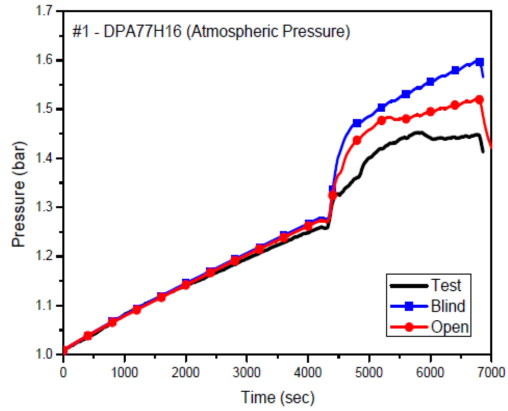

Fig. 1. Pressure buildup of HM-2 test.

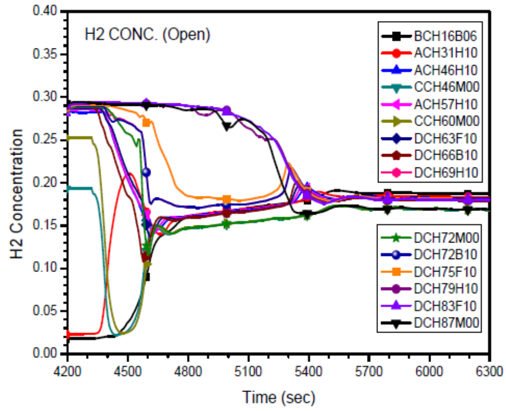

Fig. 2. Hydrogen distribution of phase 2, predicted in the open calculation. Each legend was named in accordance with the measurement in the test [2].

2.2 Phase 2 – Steam Injection and Erosion Process

During phase 2 of the experiment, because of steam plume released from a nozzle located in the lower plenum, an erosion process of the stratified layers occurred in the dome region. In phase 2, two different thermal hydraulic processes were observed, subdividing phase 2 into phase 2a and phase 2b. In phase 2a (for 500 seconds) the hydrogen concentration in the inner cylinder decreased as soon as the steam injection started and a stagnation of the flow in the inner cylinder was observed. When the flow velocity at the upper exit of the inner cylinder was greater than 1.5m/s at 4,800sec (time T2), phase 2b was initiated with the onset of natural convection from the inner cylinder to the annulus of the test vessel. Then, the circulating flow mixed the atmosphere and eroded the stratified layer of the dome region from the lower part.

Fig. 3 shows the flow velocity measured at the upper exit of the inner cylinder. While the time T2 measured in the experiment was about 4,800sec, that of MELCOR prediction of T2 was about 4,370sec (phase 2a for 50 seconds) and 4,520sec (phase 2a for 200 seconds) for the blind and open calculation, respectively. By increasing the number of vertical nodes, the stagnation of steam plume in the inner cylinder could have been weakly simulated. After the onset of natural convection the measured velocity increased gradually, but in the code simulations nearly constant low velocity was observed. This is mainly because of the lack of forced momentum source in the modeling of steam injection.

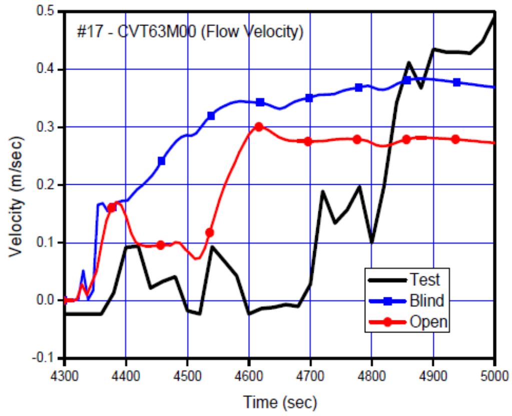

Fig. 3. Upward velocity of steam plume at the upper end of the inner cylinder at the beginning of phase 2

In the experiment, an orderly erosion process was observed apparently from the measurements of local hydrogen concentrations and atmospheric temperatures. Phase 2a is clearly found from both the hydrogen concentrations of CCH46M00 and CCH60M00 and corresponding atmospheric temperatures. As described in the velocity profile, in the open calculation, a similar erosion process could be simulated as shown in Fig. 2. According to the atmospheric temperatures and hydrogen concentrations, the erosion process was finished at about 5,400sec (at about 4,700sec in blind calculation), while it was at 5,840sec in the experiment. Differences between the experiment and open calculation could be found in the evolution of the erosion process. In the concentration profile the erosion process in the lower dome region was finished within a short period but it propagated with relatively low speed. In addition, when the erosion process was completed, a thermal stratification was found in the calculation results. This could be explained again in association with the momentum of the steam plume. An appropriate modeling method should be studied in case a fluid jet has to be considered in the code application.

Fig. 4 illustrates the erosion process resulted from blind and open calculations with MELCOR code as well as the experiment. The data was evaluated using a proposed method by the Project in which the time was checked when the hydrogen concentration was 28% during the erosion process in phase 2b. Using a detailed nodalization in vertical direction, the open calculation results showed better agreement with the experiment than in the blind case. However, because of the relatively low maximum hydrogen concentrations in the dome region at the end of phase 1, the calculation results are still located at the left hand side from that of the experiment in the figure.

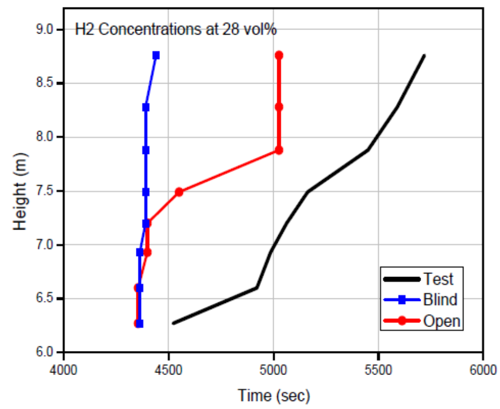

Fig. 4. Prediction of erosion process by buoyant steam against the stratified atmosphere in phase 2.

3. Conclusions

Several calculations have been executed using the MELCOR 1.8.5 code to improve the calculation results with the open data of phase 2 of HM-2 experiment. In the open calculation, major efforts were made in testing the nodalization effect. With more detailed discretization of the test vessel in the vertical direction, the prediction results of MELCOR code dramatically improved especially in simulating both the stagnation period of phase 2a and erosion process of hydrogen layer in the dome region in phase 2b. However, the problem of the difficulty in simulating the directional mass and energy release should be technically resolved in order to apply the MELCOR code to similar problems in nuclear power plants.

By participating in the benchmark study led by OECD-NEA THAI Project, we could obtain some important characteristics and behavior in the simulation with MELCOR code. The information will be kept in mind in the future studies and in the regulatory works using the code.

REFERENCES

[1] J.J. Lee, Evaluation of MELCOR Code for THAI-HM2 Test, The 10th Korea-Japan Joint Workshop on PSA, Jeju, Korea, 2009.

[2] T. Kanzleiter, K. Fischer, Quick Look Report (No. 150 1326-HM-2 QLR Rev.1): Helium/Hydrogen Material Scaling Test HM-2, Becker Technologies GmbH, 2007.