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Preliminary H_2 Combustion Analysis in the Containment of APR1400 for SBLOCA Accident using a Multi-Dimensional H_2 Analysis System

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) established a multi-dimensional hydrogen analysis system for evaluating a hydrogen release, distribution and combustion in the containment of a nuclear power plant using MAAP, GASFLOW, and COM3D [1]. The COM3D analyze an overpressure buildup resulting from a propagation of hydrogen flame along the structure and wall in the containment using the hydrogen distribution result calculated by the GASFLOW. The MAAP evaluates a hydrogen source during a severe accident and transfer it to the GASFLOW. We performed a hydrogen combustion analysis using the multi-dimensional hydrogen analysis system for a station blackout (SBO) accident under the assumption of 100% metal-water reaction in the reactor vessel [2]. The COM3D results showed that the pressure buildup was about 250 kPa because the flame speed was not increased above 300 m/s and the pressure wave passed through the open spaces in the large containment. To increase the reliability of the COM3D calculation, it is necessary to perform the hydrogen combustion analysis for another accident such as a small break loss of coolant (SBLOCA).

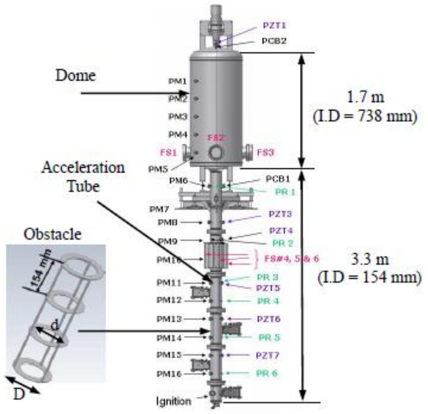
2. Methodology of the COM3D Analysis

2.1 Numerical Models in the COM3D [3]

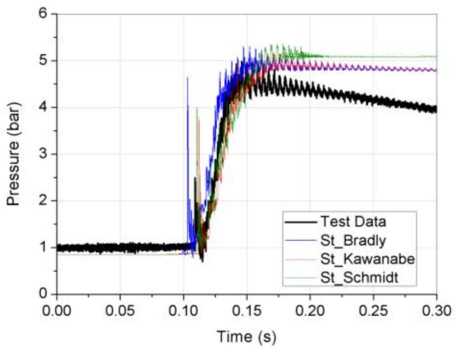
The COM3D is a fully explicit finite-differences code for solving the compressible Navier-Stokes equations in three-dimensional Cartesian space. The COM3D utilizes a set of transport equations for every gas species and for total energy, mass and momentum. For modeling of a turbulence flow during the hydrogen combustion, a Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) model are implemented in the COM3D. The COM3D has a recently developed combustion model KYLCOM+ which uses the forest fire algorithm with the burning velocity model.

2.2 Proposed Analysis Methodology of the COM3D

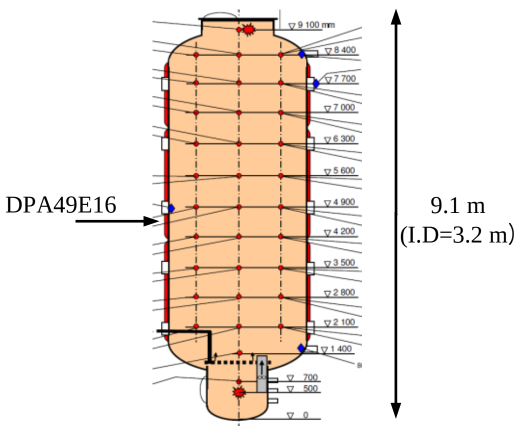
We established the COM3D analysis methodology (Table 1) on the basis of the COM3D calculation results (Fig, 1) against the test data of ENACCEF and THAI [4,5]. The proposed analysis methodology accurately predicted the peak overpressure with an error range of approximately ±15%. However, the COM3D analysis was not performed for the hydrogen combustion under the condition of the steam presence.



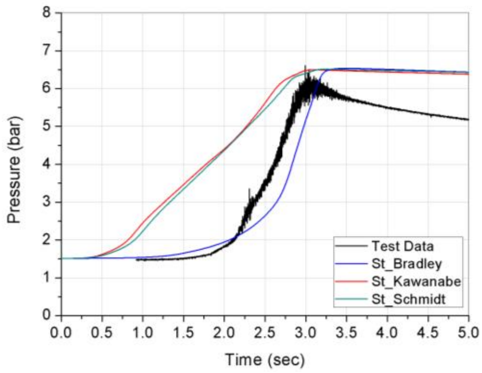
(a) ENACCEF Facility
(Test condition: H2 13%, Blockage Ratio 0.63)



(b) Comparison of Pressure Behavior at PCB1 between Test Data and COM3D results (ENACCEF)



(c) THAI Facility (Test condition: H2 9.97%, No Obstacle)



(b) Comparison of Pressure Behavior at DPA49E16 between Test Data and COM3D (THAI)

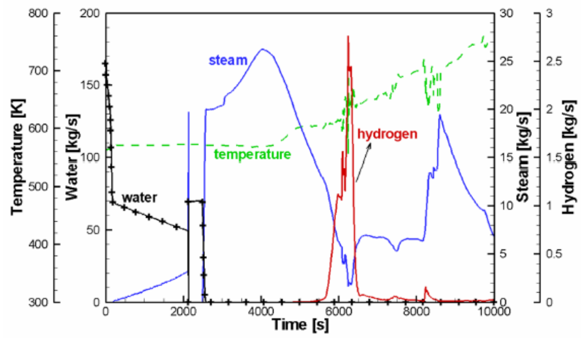
Fig. 1. COM3D Results for the ENACCEF and THAI Test

Table 1. COM3D Analysis Methodology

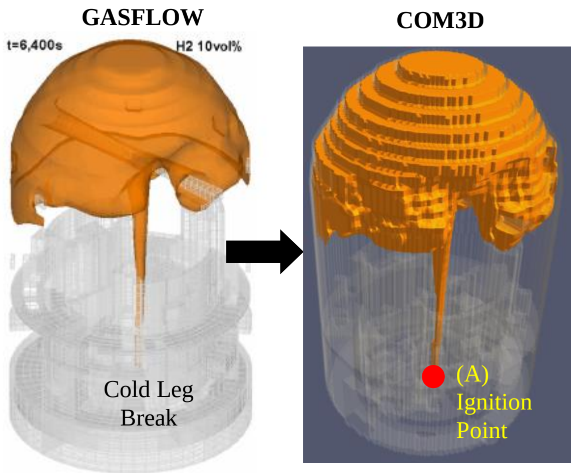
- Explicit solver : 2nd order TVD entropy based solver
- Combustion model : KYLCOM+
- Turbulent flame speed model : Bradley/Kawanabe/Schmidt
- Turbulent model : Standard k-ε
- Wall function : Low Re number + Launder Sharma
- Slip wall condition
- CFL number : < 0.9, RED number : < 0.4
- Mesh sensitivity results : Reference [5]
- Prediction uncertainty for peak pressure : ±15%

3. COM3D Analysis for a SBLOCA Accident

A COM3D analysis was performed to evaluate an overpressure buildup owing to a hydrogen flame acceleration in the APR1400 containment using the calculated hydrogen distribution by the GASFLOW for a SBLOCA accident under the assumption of a 100% metal-water reaction in the reactor vessel. The break position was assumed as an upper part of the cold leg pipe. Fig. 2(a) shows the predicted hydrogen and steam generation rate by the MAAP. The grid model representing the APR1400 containment, as shown in Fig. 2(b), was also transferred from the GASFLOW to the COM3D by reducing the cell length to approximately 0.5 m. Therefore, a total of 1,453,025 hexahedral cells in the grid model were generated. The cell length was determined to accurately resolve the pressure wave propagation generated from the combusted region [6] and model the important structures in the containment. The wall condition with a constant temperature of 298 K was applied to the inner surface of the grid model. The ignition points were assumed at the hydrogen release location around the cold leg in Fig. 2(b). An ignition process was modeled by the use of a hot spot region with a radius of 0.5 m where the hydrogen flame propagates with the laminar flame speed according to the hydrogen concentration. The analysis methodology (Table 1) chosen through the simulation of the ENACEEF and THAI tests was used for this calculation.



(a) Hydrogen and Steam Generation Rate (MAAP)



(b) Iso-surface of H_2 10% (GASFLOW and COM3D)

Fig. 2. MAAP and GASFLOW Results for the SBO Accident

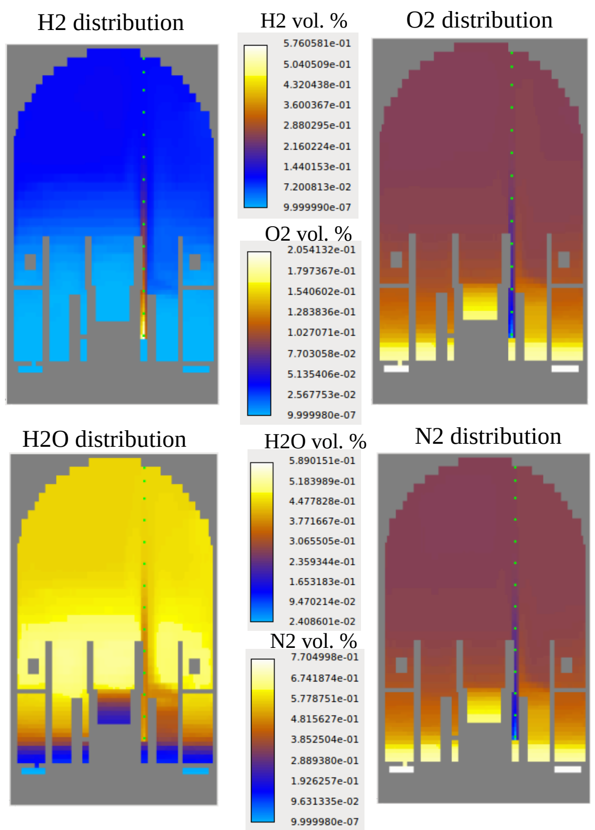
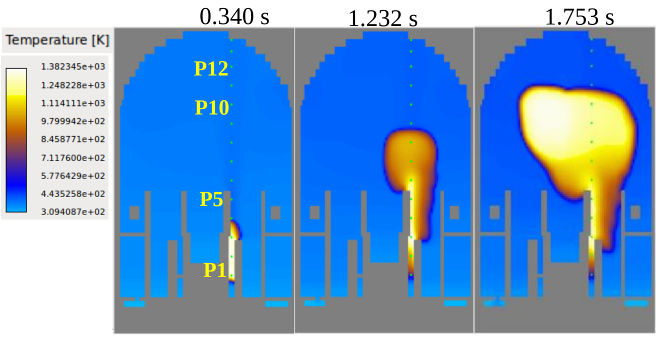
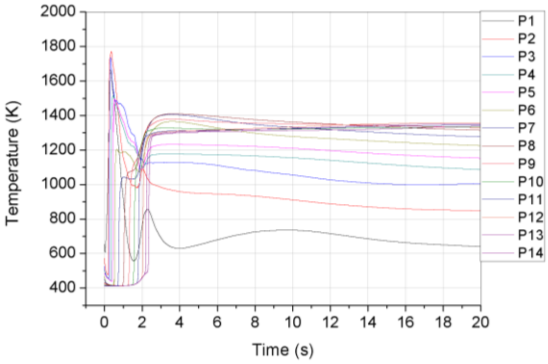


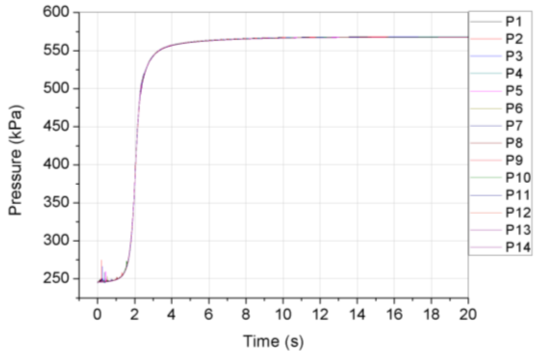
Fig. 3. Initial Conditions for the COM3D Calculation



(a) Temperature Distribution



(b) Temperature Behaviors from P1 to P14



(c) Pressure Behavior from P1 to P14

Fig. 4. COM3D results of the SBLOCA Accident

The COM3D results show that the hydrogen flame is propagated to approximately 55 m along the vertical direction in about 2.0 s after the start of the ignition (Figs. 4(a) and (b)). The calculated flame speeds is increase to about 100 m/s. The flame arrival time needed for calculating the flame speed was defined as the instant when the gas temperature increased to 800 K at the locations of P1 to P14. However, the increased pressures owing to the flame acceleration are approximately 310 kPa. These low pressure increases may have resulted from the low flame speed developed along the vertical direction. In particular, the hydrogen flame is slowly accelerated in the region from P1 to P3 even though the hydrogen concentration is approximately 35-57%. This may be caused from the fact that the hydrogen-air chemical reaction is constrained by the low oxygen concentration of approximately 2-7% in the region from P1 to P3 because a steam with 30-40% locates in this region (Fig. 3). This may mean that the maximum hydrogen concentration to react with the oxygen is approximately 14%. In addition, the pressure wave developed from the slow flame acceleration passed through the open spaces in the large containment.

4. Conclusions and Further Work

KAERI performed a hydrogen combustion analysis for a SBLOCA accident using the multi-dimensional hydrogen analysis system under the assumption of 100% metal-water reaction in the reactor vessel. From the COM3D results, we can know that the pressure buildup was approximately 310 kPa because the flame speed was not increased above 100 m/s owing to the high steam concentration and low oxygen concentration in the hydrogen distributed region of the containment. The predicted maximum overpressure in the SBLOCA accident is similar to that of the COM3D results for the SBO accident [2]. Thus, we found that the maximum overpressure due to the hydrogen combustion in the containment may depend on the amount of hydrogen mass released from the reactor vessel.

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