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

H_2 Combustion Analysis in the Containment of APR1400 for SBO 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[1,2]. The GASFLOW calculates the hydrogen distribution in the containment with a hydrogen source evaluated by the MAAP during a severe accident. 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[3]. In order to assure the containment integrity of APR1400, it is necessary to evaluate an overpressure buildup due to the hydrogen combustion in the containment by the multi-dimensional hydrogen analysis system.

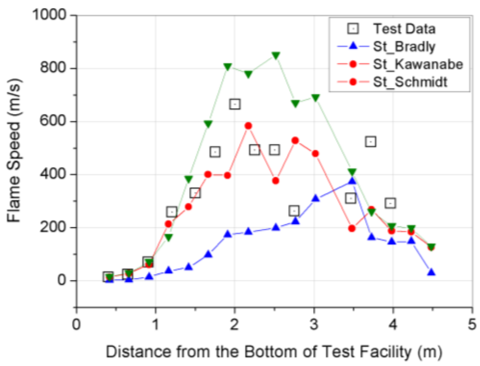
2. Numerical Models in the COM3D Code [3]

COM3D is a fully explicit finite-differences code on the basis of the well established numerical methods 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 for calculating the hydrogen flame propagation.

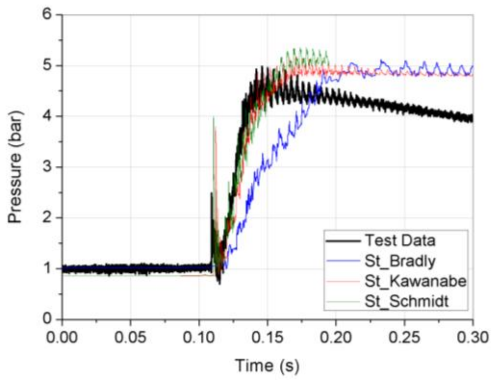
3. COM3D Analysis for Hydrogen Combustion

3.1 COM3D Analysis for ENACCEF Test

KAERI first calculated for the ENACCEF test [4] with a hydrogen concentration 13% and an obstacle blockage ratio of 0.63 using the COM3D to see the uncertainty of the COM3D prediction according to a turbulent flame speed model[3]. The KYLCOM+ model with the turbulent flame speed correlations of Bradly, Kawanabe, and Schmidt were used to simulate the hydrogen flame propagation in the COM3D calculation. A turbulent flow was modeled using the standard k-ε turbulent model. The time step size for the COM3D calculations was automatically controlled to assure a CFL(Courant-Friedrichs-Lewy) number 0.9[3]. The number of cell generated for the hydrogen combustion in the grid model is 439,217. The comparison between the COM3D result and test data showed that the KYLCOM+ model with the Kawanabe correlation accurately predicted the flame speed and peak pressure with an error range of about ±15% (Fig. 1). However, the COM3D results overpredicted the pressure behavior from 0.15 s to 0.30 s in Fig. 1(b). This overestimation may have resulted from the higher flame temperature owing to the less heat transfer from the hydrogen flame to the test facility wall because the COM3D does not have a steam condensation model along the wall.



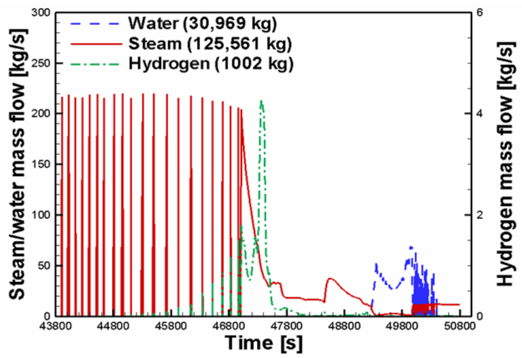
(a) Flame Speed



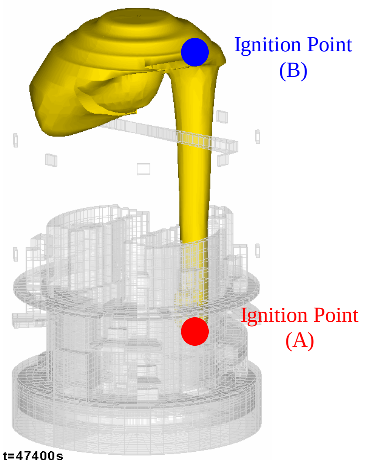
(b) Pressure Behavior
Fig. 1. COM3D Results for ENACCEF Test

3.2 COM3D Analysis for the H_2 Combustion in the APR Containment under the SBO 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 station blackout accident under the assumption of a 100% metal-water reaction in the reactor vessel. Fig. 2(a) shows the predicted hydrogen and steam generation rate at the condition of the 100% metal-water reaction 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 for the hydrogen combustion. The cell length was determined to accurately resolve the pressure wave propagation generated from the combusted region[5] and model the important structures in the containment. The wall condition with a constant temperature of 298 K was applied to the outer surface of the grid model. The ignition points were assumed at around the hydrogen release location in the steam generator compartment (A) and around the top location of the hydrogen plume (B) as shown 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-air chemical reaction takes place. The analysis methodology chosen through the simulation of the ENACEEF test was used for this calculation.



(a) Hydrogen and Steam Generation Rate (MAAP)

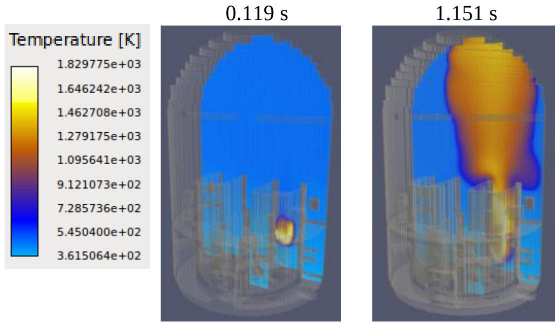


(b) Iso-surface of H_2 Concen. 10% (GASFLOW)

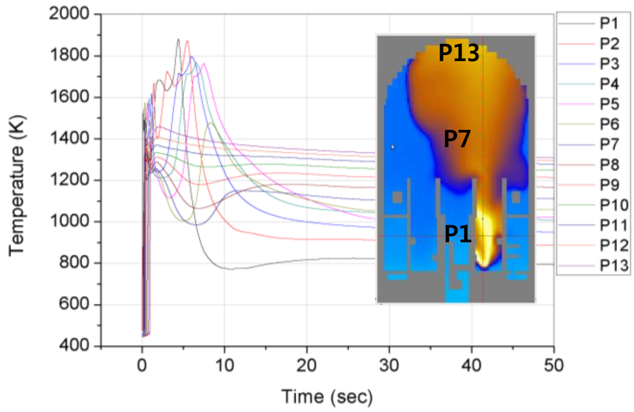
Fig. 2. MAAP and GASFLOW Results for the SBO Accident

Table 1. COM3D Analysis Condition in the Containment

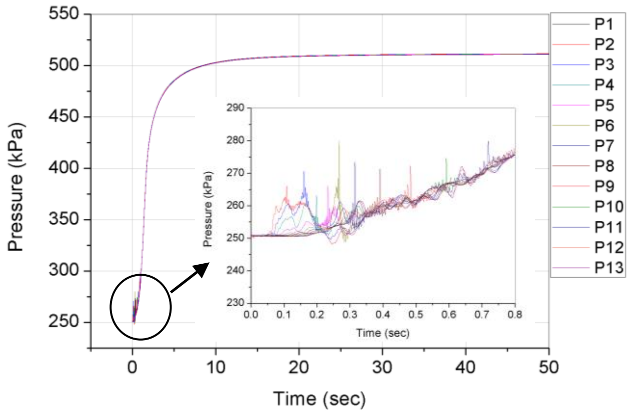
Case	H_2 Distribution	H_2 Con. (%)	Mesh Size (cm)	Ignition Point
1	Gasflow result	0 - 44.4	50	A
2	Gasflow result	0 - 44.4	50	A & B



(a) Temperature Distribution



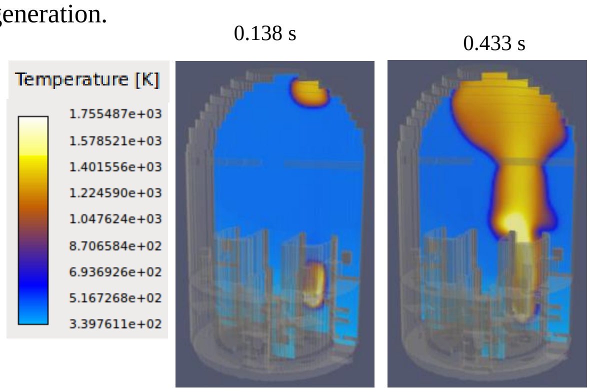
(b) Temperature Behaviors from P1 to P13



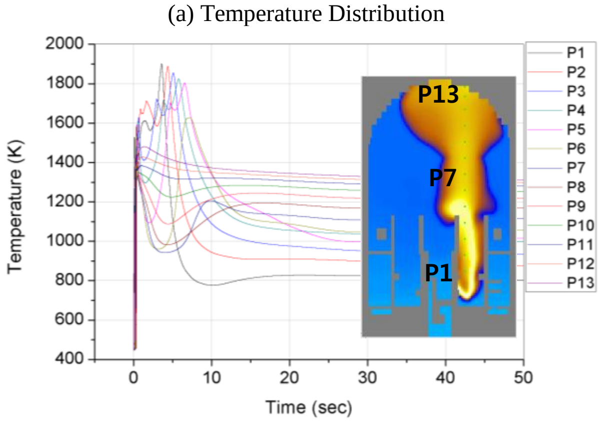
(c) Pressure Behavior from P1 to P13

Fig. 3. COM3D results of Case-1

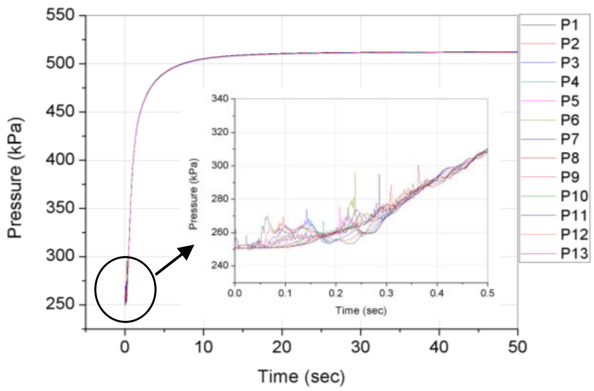
The COM3D results of Case-2 show that the hydrogen flame is propagated to approximately 60 m along the vertical direction in about 1.10 s after the start of the ignition (Figs 3. (a) and (b)). The calculated flame speeds of Case-1 is increase to about 300 m/s. The flame arrival time needed for calculating the flame speed was defined as the instant when the gas temperature increased to 1000 K at the locations of P1 to P13. However, the increased pressures owing to the flame acceleration are about 250 kPa in Case-1. The initial pressure of Case-1 is about 250 kPa. These low pressure increases may have resulted from the low flame speed along the vertical due to the low turbulence generation.



(a) Temperature Distribution



(b) Temperature Behaviors from P1 to P13



(c) Pressure Behavior from P1 to P13

Fig. 4. COM3D results of Case-2

The COM3D results of Case-2 show that the hydrogen flame is accelerated to approximately 30 m along the vertical direction from the top and bottom regions in about 0.4 s after the start of the ignition (Figs 4. (a) and (b)). The increased pressures owing to the flame acceleration are about 250 kPa in Case-2. The initial pressure of Case-1 is also about 250 kPa. These low pressure increases may have resulted from the pressure wave generated at the combusted region passed through the open spaces between the structures in the large containment. The calculated peak pressures of Case-1 and Case-2 are reasonable on the basis of the measured peak pressure in the flame test performed by Sandia National Laboratories (SNL) [6].

4. Conclusions and Further Work

KAERI performed a hydrogen combustion analysis 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 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.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT, and Future Planning) (No. 2012M2A8A4025889)

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