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Preliminary COM3D Analysis for H_2 Combustion in the APR1400 Containment

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) established a numerical analysis system for evaluating an overpressure buildup owing to a hydrogen combustion in the containment of a nuclear power plant by importing COM3D from KIT in Germany [1, 2]. The COM3D has been currently used in the simulations of the combustions and explosions, together with the system of industrial risk mitigation of hydrogen and burnable gases in nuclear containment and auxiliary buildings [3]. In order to assure the containment integrity of APR1400, it is necessary to evaluate an overpressure buildup resulting from a propagation of hydrogen flame along the structure and wall in the containment during a severe accident using the COM3D

2. Numerical Methods of the COM3D Code [3]

The 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 the turbulence flow in the hydrogen combustion, Reynolds Averaged Navier-Stokes (RANS) and Large Eddy Simulation (LES) model are implemented in the COM3D. A set of combustion models from classic model such as Eddy Brake-Up to the newest developments KYLCOM+ is available in the COM3D. The KYLCOM+ 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 with the hydrogen concentration of 13% and an obstacle blockage ratio of 0.6 using the COM3D before applying the COM3D analysis into the APR1400 containment to see the uncertainty of the COM3D prediction [2]. The KYLCOM+ model with Kawanabe turbulent flame speed model [3] was used to simulate the hydrogen flame propagation in the COM3D calculation. A turbulent flow was modeled by the standard k-ε turbulent model. The time step size for the COM3D calculations was automatically controlled to assure a CFL number 0.9 [3]. The comparison of the peak pressure between the COM3D result and test data showed that the COM3D overpredicted the peak pressure of the test results with an error range of about 20% (Fig. 1). This overestimation may be 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 no radiative heat transfer model.

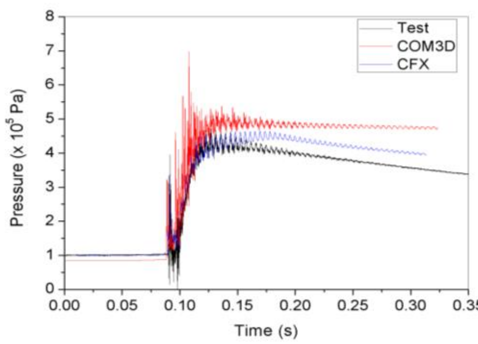


Fig. 1. Peak pressure predicted by COM3D [2]

3.2 COM3D Analysis for the H_2 Combustion in the APR Containment under Assumption of H_2 Concentration

KAERI analyzed the hydrogen flame acceleration in the upper region of the Passive Auto-Catalytic Recombiners (PARs) in the APR1400 containment under assumption of the hydrogen concentration 13% and 30% to understand the characteristics of the hydrogen flame propagation in a real plant geometry according to the hydrogen concentration (Table 1, Fig. 1). The analysis methodology applied in the simulation of the ENACEEF test was used for this calculation. The ignition point was assumed at the above location of the PAR as shown in Fig. 2(a). The COM3D results (Fig. 3(a)) showed that the hydrogen flame speed in Case-1 was increased to about 20 m/s at P7, whereas that of Case-2 was accelerated to about 1400 m/s at P7. This big difference may be explained by the fact that more turbulence generated in Case-2, owing to the higher combustion energy, when the flame passes along the containment wall greatly accelerated the flame speed when compared to that of Case-1. The difference of the flame speed induced that the predicted peak pressures at P7 in Case-1 and Case-2 are about 200 kPa and about 1400 kPa, respectively Figs. 3 (b) and (c)). 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) [4].

Table 1. COM3D Analysis Condition in the APR1400 Containment

Case	H_2 Distribution	H_2 Con. (%)	Mesh Size (cm)	H2 Mass (kg)
1	Assume	13	63.5	174.6
2	Assume	30	63.5	395.4
3	Gasflow result	0 - 44.4	25	605.5
4	Gasflow result	0 - 44.4	25	605.5

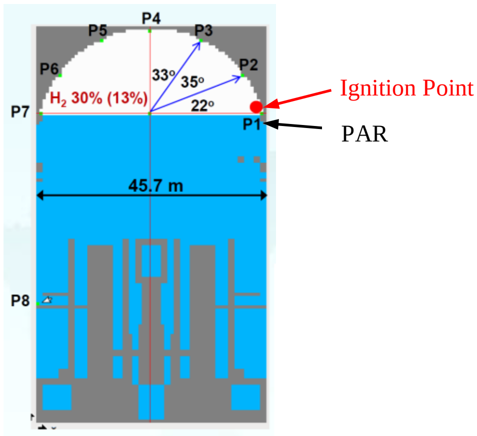
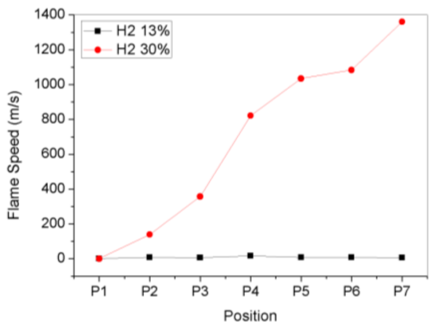
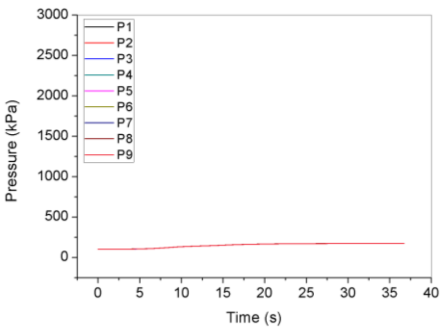


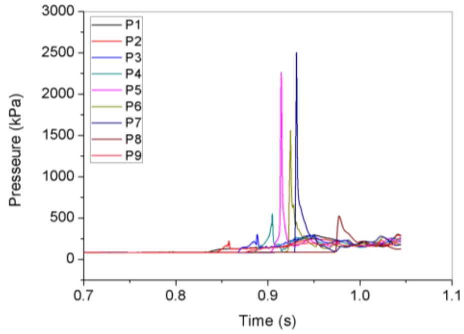
Fig. 2. Initial H_2 concentration and side view of the grid model of Case-1 and Case-2



(a) Flame speed from P1 to P7 of Case-1 and Case-2



(b) Pressure from P1 to P9 of Case-1



(c) Pressure from P1 to P9 of Case-2

Fig. 3. COM3D results of Case-1 and Case-2

3.3 COM3D Analysis for the H_2 Distribution in the APR Containment calculated by GASFLOW

A preliminary 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 assumption of 85% metal-water reaction in the reactor vessel [5]. The grid model representing the APR1400 containment, as shown in Fig. 4, was also transferred from the GASFLOW to the COM3D by reducing the cell length to approximately 0.25 m. Therefore, a total of 11,746,882 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 [6] 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 was assumed at about the top location of the hydrogen plume (Case-3) and about the hydrogen release location in the Steam Generator (SG) compartment as shown in Fig. 4(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.

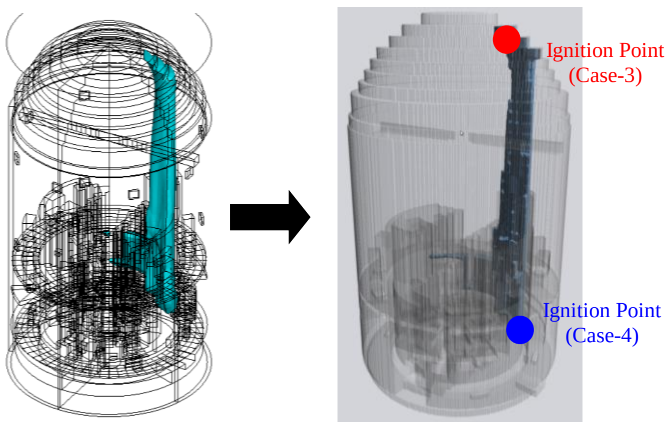
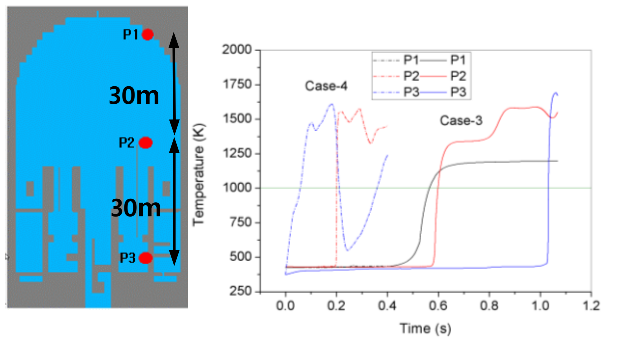
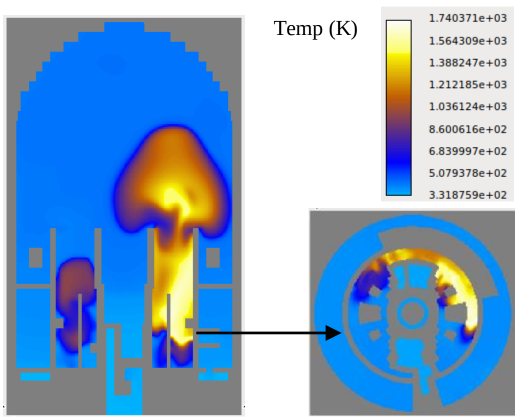


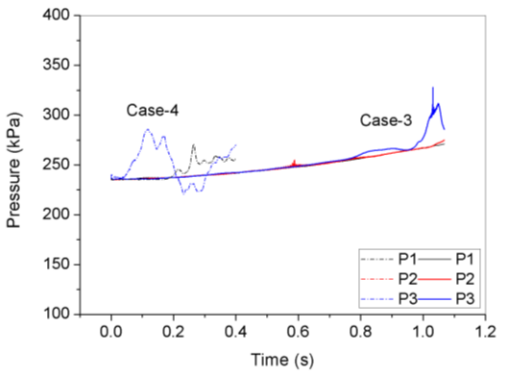
Fig. 4. Iso-surface of hydrogen concentration 10% and grid model transferred from GASFLOW



(a) Temperature behavior at P1, P2, and P3



(b) Temperature distribution of Case-4 (0.40 s)



(c) Pressure behavior at P1, P2, and P3

Fig. 5. COM3D results of Case-3 and Case-4

The COM3D results, as shown in Fig. 5, showed that the hydrogen flame was propagated to approximately 60 m along the vertical direction and about 30 m along the radial direction in about 1.10 s (Case-3) and about 0.4 s (Case-4) after the start of the ignition (Figs. (a) and (b)). The calculated flame speeds of Case-3 and Case-4 are about 890 m/s and about 200 m/s, respectively. 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 P3. However, the increased pressures owing to the flame acceleration are about 325 kPa in Case-3 and about 280 kPa in Case-4. The initial pressure of both cases was about 240 kPa. These low pressure increases may be resulted from the low flame speed along the vertical and radial direction due to low turbulence generation. In addition, the pressure wave generated at the combusted region passed through the open spaces between the structures in the large containment.

4. Conclusions and Further Work

KAERI performed the hydrogen combustion analysis using the COM3D code with the initial hydrogen distribution calculated by the GASFLOW under assumption of 85% metal-water reaction in the reactor vessel. From the COM3D results, we can know that the pressure buildup was about 100 kPa because the flame speed was not increased above 1000 m/s and the pressure wave passed through the open spaces in the large containment. However, more detailed analysis on the COM3D results will be conducted to find the exact reason of the low pressure buildup.

ACKNOWLEDGMENTS

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