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CFD Analysis for a Hypothetical H_2 Explosion Accident between the H_2 Production Facility and the HTTR in JAEA

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1. Introduction

A safety distance between a Very High Temperature Gas-Cooled Reactor (VHTR) and a H_2 production facility is usually determined by basing it on the peak overpressure under the assumption of a hypothetical H_2 explosion accident [1]. We developed a CFD analysis methodology using a Computational Fluid Dynamics (CFD) code for predicting the overpressure of hydrogen explosion and pressure wave propagation toward the VHTR [2]. We found out that a CFD code with a turbulent combustion model and one-step chemical reaction such as an Eddy Dissipation Model (EDM) [2] can be a useful tool to predict an overpressure buildup due to obstacle geometry in a hydrogen explosion. To confirm the applicability of the developed CFD analysis methodology to the evaluation of the safety distance between a VHTR and a hydrogen production facility, it is necessary to apply the proposed CFD analysis methodology into the H_2 production facility and HTTR in JAEA.

2. Developed CFD Analysis Methodology on the Basis of SRI's H_2 Explosion Test Results

Stanford Research Institute (SRI) International performed a hydrogen explosion test in an open space by varying the mixture volumes of hydrogen and air, the concentration of hydrogen gas, the ignition method, the ambient temperature, the presence of an obstacle, and the obstacle geometry configuration [3]. In particular, they used a complicated obstacle with an array of a steel tube to accelerate hydrogen flame in the test facility with a hydrogen-air mixture volume of 5.6 m^3 [3].

Table 1. Developed CFD Analysis Methodology [2]

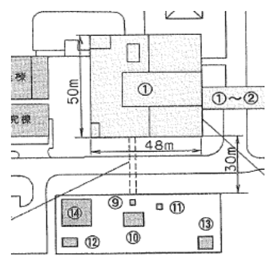
- ANSYS CFX-11 (pressure based coupled algorithm)
- Standard k-ε model (scalable wall function)
- Mesh length (10% of the pitch in an array of a steel tube)
- Time step size: CFL < about 1.2
- Eddy dissipation model
  - A = 10, B = 0.8 for H_2 30% (stoichiometry condition)
  - A = 7, B = 0.8 for H_2 20% and H_2 58%
- Spark ignition model for 40 J was developed.

Through the comparison of the simulated results with the test results, we found out that the proposed CFD analysis methodology enables us to predict the flame front time of arrivals and peak overpressure within an error range of about ±30% [2].

3. CFD Analysis

3.1 Scenarios of hypothetical H_2 explosion accident

The following physical principals were considered in the construction of three accident scenarios (Table 2) to confirm that the application results predicted by the developed CFD analysis methodology are physically reasonable: (1) a larger hydrogen-air mixture volume induces a larger peak overpressure around a hydrogen explosion site and (2) a blast wave changes its direction or loses its energy after it collides with a building in an air environment. The obstacle configuration and the test conditions were quoted from the small-scale obstacle used in SRI's hydrogen explosion test facility [3] to reduce the uncertainty of the peak overpressure predicted by the CFD analysis in the hydrogen production facility.



1: HTTR
9: Steam Reformer
10: Heater
11: Steam Generator
12: Cooling Tower
13: Flare Stack
14: Administration

Figure 1. Building Configuration in the H_2 Facility

Table 2. Scenarios of H_2 Explosion Accidents

	Accident Sequence
Case-1	- H_2 explosion at the front region of the SR - H_2-Air mixture: 2.78 m^3, 30% - Ignition location : bottom of the SR and 40 J
Case-2	- H_2 explosion at the front region of the SR - H_2-Air mixture: 8.45 m^3, 30% - Ignition location: bottom of the SR and 40 J
Case-3	- H_2 explosion at the rear region of the SR - H_2-Air mixture: 2.78 m^3, 30% - Ignition location: bottom of the SR and 40 J

*SR: Steam Reformer

3.2 Grid Model, Initial and Boundary Conditions

Two 3-dimensional and half symmetric grid models for the CFD calculation of the hypothetical hydrogen accident scenarios were generated based on JAEA technical reports [4]. The mesh lengths for the hydrogen explosion region, its environment region, and the far field region for the blast wave propagation were 1cm, 4cm, and 25cm, respectively. The number of generated meshes in the grid model for Case-1 and Case-2 was 15,114,132 cells, and for Case-3 it was 17,523,212 cells. The boundary and initial conditions, including the spark ignition model, were given according to the methods developed in the CFD analysis methodology [2].

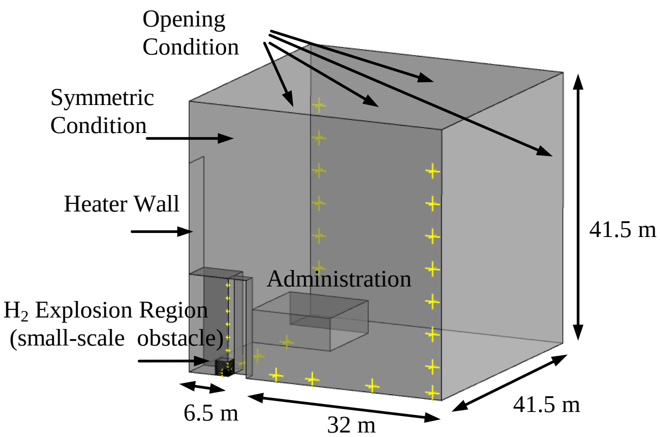


Figure 2. Grid Model and Boundary Conditions for Case-3

3.3 Discussion on the CFD Analysis Results

The difference in the hydrogen-air mixture volume between Case-1 and Case-2 (Table 2) gives rise to the differences in the locations of the hydrogen flame termination points. The difference in the final locations of the hydrogen flame results in the different locations of the blast wave initiation. This difference also induces the difference between Case-1 and Case-2 in the magnitude and duration of the blast wave propagation to the HTTR. The blast waves of Case-2 propagate to the HTTR faster and more forcefully than those of Case-1 do.

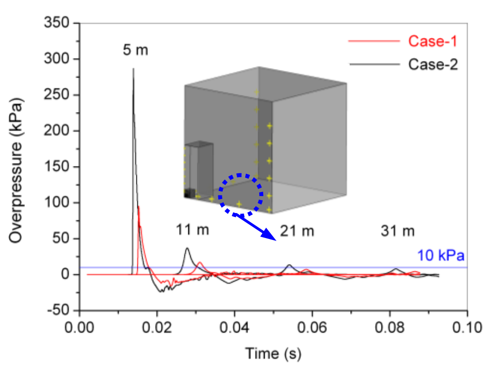


Figure 3. Comparison of overpressure at various locations in Case-1 with that in Case-2

The only difference between Case-1 and Case-3 is the hydrogen explosion location in the accident scenario (Table 2). This difference affects the pathway of the blast waves from the hydrogen explosion because the heater building of the height of 32 m is located at a distance of 6.5 m from the rear of the steam reformer [4]. After escape from the steam reformer, the blast wave starts to propagate along the direction of the HTTR. Another blast wave propagates in the direction of the administration building after the hydrogen explosion is finished. Some of these blast waves are directed toward the HTTR after passing the width of the steam reformer. Therefore, the CFD analysis results show the two peaks of the overpressures at 5 m and 11 m along the direction of the HTTR for their pressure histories (Fig. 4).

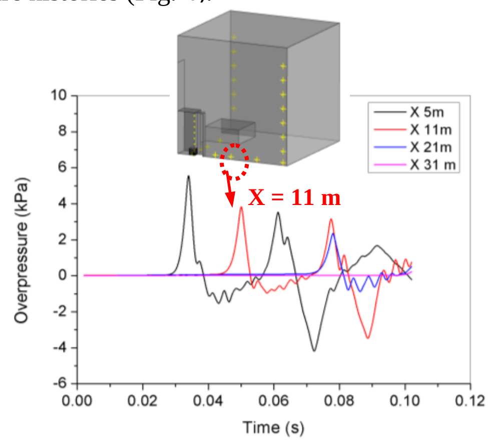


Figure 4. Comparison of overpressure at various locations in Case-3

4. Conclusions

We confirmed the applicability of the developed CFD analysis method to the evaluation of the safety distance between a VHTR and a hydrogen production facility through the CFD analysis conducted on the HTTR and the hydrogen production facility in JAEA. The applications study showed physically reasonable results when compared to the test data performed by SRI International.

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