Peak Overpressure Predictions for a SRI Test by Correlation Methods and a CFD Analysis

Hyung Seok Kang*, Keun Sang Choi, and Sang Doug Park[1]
KAERI, 111, Daedeok-daero, 989 Beon-gil, Yuseong-Gu, Daejeon, 34057, Republic of Korea
[1]Seoul National University Nuclear Energy Policy Center, Seoul 08826, Korea
[*]Corresponding author: hskang3@kaeri.re.kr

1. Introduction

A hydrogen production facility, which uses a water electrolysis method, connected a pressurized water reactor (PWR) is being considered for construction in Uljin-gun, Gyeongsangbuk-do according to Korean regulations and technical standards [1]. One of the regulations may be the safety distance between the PWR and the hydrogen production facility [2]. The installation of a barrier around the hydrogen production facility is also considered to reduce the safety distance between two plants [2,3]. The determination of the safety distance may be performed easily based on the overpressure limit, if an overpressure due to a gas explosion is predicted by a correlation [2]. The Trinitrotoluene (TNT) equivalent method and the Multi-Energy Method (MEM) are used widely for the prediction method of a peak overpressure [2]. A Computational Fluid Dynamics (CFD) analysis may also be used as an accurate evaluation tool to provide a 3-dimesnional information of an overpressure if a proper analysis methodology is chosen [2,3]. To evaluate an applicability of each method, it is necessary to predict the measured overpressures in a hydrogen explosion test using the methods.

2. Peak Overpressure Prediction for a SRI Test

2.1 Test Facility

Stanford Research institute (SRI) performed a hydrogen explosion test, Test 2-1, using a hydrogen-air mixture volume of 5.6 m^3 with a small-scale obstacle under a stoichiometric condition of 30 vol. % at an ambient temperature of 298.75 K in an open space [4]. In the test, an electric spark device, its equivalent energy was 40 J, at the lower location of the central region in the tent was used to ignite the hydrogen-air mixture in the tent (Fig. 1). The measurement error of the pressure sensors used in the test were approximately 5% [4].

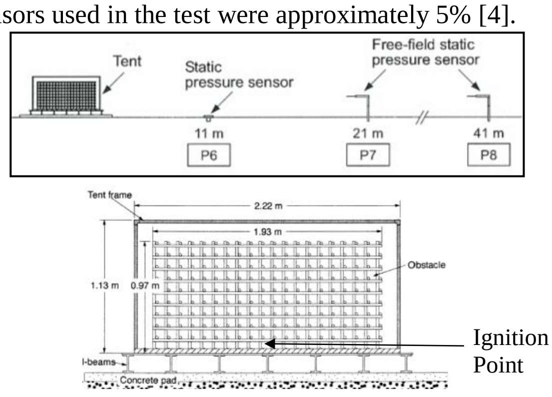

Fig. 1. SRI test facility [4]

2.2 Peak Overpressure Prediction by Correlation Methods and a CFD analysis

The predicted peak overpressures along the distance from the hydrogen explosion region by the TNT, MEM, and CFD analysis are shown in Fig. 2 and Table 1. For the TNT calculation, we used the chart of the TNT equivalent method [2,5] and applied the conversion ratio (η) of 1 to obtain the TNT equivalent mass (W_{TNT}) in Eq. (1) from the hydrogen mass located in the tent region on the basis of a recommended value in the reference report [6]. The term of Q in Eq. (1) represents an amount of the released thermal energy in the hydrogen-air chemical reaction. In addition, we calculated the peak overpressures using an air blast method (Eqs. (2) to (4)), which was used for calculating the safety distance between a nuclear power plant and a hydrogen production facility in U.S. by Sandia National Laboratories [6]. In Eq. (4), R_D means the physical distance from the center of the detonable region, and total energy released from the mass of hydrogen contained in the detonable region, respectively [6].

The calculated peak overpressure in the tent by the TNT chart accurately predicts the measured data with an error range of approximately 3%, but the peak overpressure difference between the TNT and the test data increases from approximately 33% to 57% as the distance from the explosion site increases from 10.91 m to 41.15 m. The drawbacks of the TNT equivalent method are that the predicted overpressure value can not be obtained at very near field of the explosion site (Fig. 2). The air blast method can predict the overpressure at the distance of 0.93m from the ignition point in the tent, but it predicted 8 times higher than the measured data. As a result of this overprediction, the calculated overpressures at 1.29 m to 41.15 m, which are located at the far field from the explosion site, are also 4 – 6 times higher than the test data.

$$W_{TNT} = \eta W_{H_2} \frac{Q_{H_2}}{Q_{TNT}} \quad (1)$$

$$P^* = \frac{0.34}{(R^*)^{4/3}} + \frac{0.062}{(R^*)^2} + \frac{0.0033}{(R^*)^3} \quad (2)$$

$$P^* = \frac{P_{peak}}{P_o} \quad (3)$$

$$R^* = \frac{R_D P_o^{1/3}}{E_n^{1/3}} \quad (4)$$

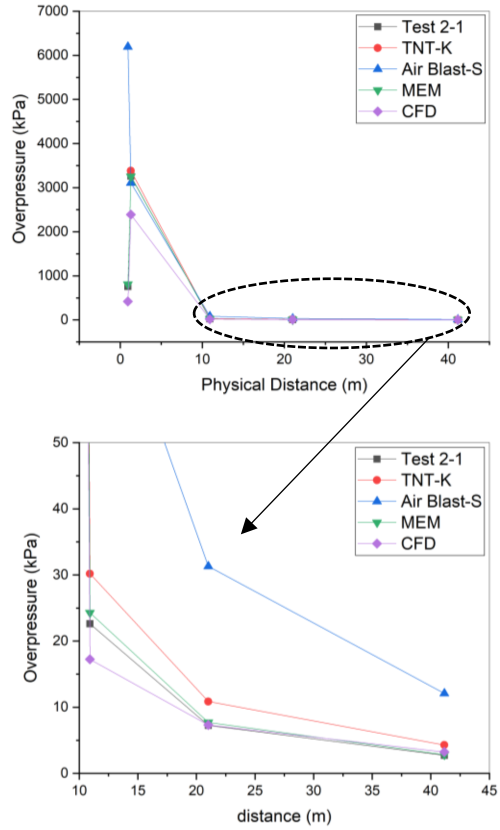

Fig. 2. Comparison between measured values of overpressure data in tests with obstacles and values predicted by the TNT, MEM, and CFD analysis

Table 1: Calculated peak overpressure results

	Physical distance [m]				
	0.93	1.29	10.91	21.01	41.15
Test	756.2	3263.6	22.6	7.2	2.7
TNT-K	N/A	3384.3	30.1	10.8	4.2
Air Blast-S	6193.8	3107.3	81.8	31.3	12.1
MEM	806.8	3253.3	24.2	7.7	2.8
CFD	421.9	2389.3	17.2	7.3	3.2

*Overpressure unit : kPa

The predicted overpressure values by the MEM show a good agreement with an error range of approximately 7%, when compared to the test results, in the range from 0.93 m to 41m because the overpressure increase in the tent by the MEM was accurately simulated using the empirical correlation (Eq. (5)) with the "Volume Blockage Ratio (VBR)" due to an obstacle and "L_p/D". The L_p/D term means the number of obstacles passed during a flame propagation, and "S_L" represents the laminar burning velocity at the given hydrogen-air concentration. Thus, if an obstacle information in a gas explosion center is not provided, the MEM does not predict the peak overpressure around the center of the gas explosion correctly. In addition, the MEM can only predict a symmetric configuration of an obstacle. Whereas, the CFD analysis using an established analysis methodology (Table 1) predicts an overpressure buildup due to a hydrogen explosion and the blast wave propagation from the near field to the far field of the hydrogen explosion site with an error range of approximately ±30%.

$$\Delta P_s = 0.84 \bullet \left(VBR \bullet \frac{L_P}{D} \right)^{2.75} \bullet S_L^{2.7} \bullet D^{0.7} \qquad (5)$$

3. Conclusions and Further Work

Through the comparison of the peak overpressures by the correlational methods and the CFD analysis with test data, it was founded that the MEM may be used effectively to estimate the peak overpressure for a gas explosion simply whereas the CFD analysis may be used as an accurate evaluation tool to provide the 3-dimesnional information on a peak overpressure around structures located at around the hydrogen explosion site. Therefore, is recommended that the risk-informed accident scenario to decide a released hydrogen mass and range, the MEM and the CFD analysis method are used together to determine the safety distance between a PWR and a hydrogen production facility using a water electrolysis device in Uljin-gun, Gyeongsangbuk-do. However, to apply this recommended method in evaluating the safety distance at a real plant in Uljin-gun, a Korea-specific regulation should be published because U.S. NRC recommends the use of the TNT equivalent method for calculating the safety distance to protect a nuclear power plant from a hypothetical gas explosion accident [6,7].

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