A Research to Determine Blast Wave Parameters

Tae-Jin Kim [a], Yoon-Suk Chang [a*], Choengryul Choi [b] and Won Tae Kim [c]
[a]*Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Gyeonggi-do 17104, Korea*
[b]*ELSOLTEC, 120 Heungdeok-jungangro, Giheung-gu, Yongin0si, Gyeonggi-do 16950, Korea*
[c]*RETEC, 382 Sinbong 1-ro, Sugi-gu, Yongin-si, Gyeonggi-do 16830, Korea*
[*]*Corresponding author: yschang@khu.ac.kr*

1. Introduction

High energy lines are generally operated higher than a temperature of 200 ºF or pressure of 275 psig, main steam system, safety injection system, residual heat removal system, and reactor coolant system of nuclear power plants are included. When a sudden rupture occurs in the high energy lines, ejection of inner fluid with high temperature and pressure causes jet impingement, pipe whip and jet reflection as well as blast wave with secondary damage of adjacent major components [1].

For this matter, ANSI/ANS 58.2 standard was established to provide design concept and requirements against the postulated rupture of the high energy line [2]. However, among the phenomena, the blast wave was not considered in the standard. USNRC also addressed that some assumptions related to high energy line break (HELB) in the standard [3], so that new assessment method should be developed under the HELB condition.

In this study, for the verification of major parameter which demonstrate the blast wave phenomena, an experimental apparatus has been constructed and test was conducted under a preliminary HELB condition. Subsequently, 3-dimensional numerical analysis was performed using TNT model which are widely used to simulate the blast wave. Finally, blast wave parameters were verified with comparing the experimental data and corresponding analysis results.

2. Experimental Set-Up

2.1 Experimental Apparatus

Fig. 1 depicts a schematic diagram designed for blast wave experiments. The apparatus consists of pressure tank, pressure vessel, rupture pipe, and target disk as shown in Fig. 2. High temperature and pressure of steam is generated at the pressure tank, and gathered at the pressure vessel. When the pressure increases at a certain value, rupture disk located at the end of the rupture pipe is ruptured. The target disk is fixed with the bottom structure, pressure distributions were measured with radial direction.

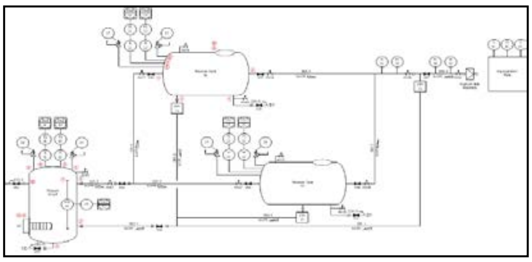

Fig. 1 Schematic diagram of experimental apparatus

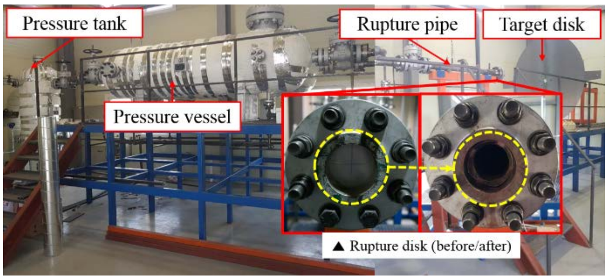

Fig. 2 Experimental apparatus for blast wave

2.2 Experimental Condition and Results

For the verification of major parameters which simulate the blast wave, experimental conditions were set. The distance between target disk and rupture pipe was 1.0 m. The rupture disk was broken at 2.5 MPa. At the target disk, as shown in Fig.3, pressure was measured at four representative points. Fig. 4 represents the pressure distributions of the target disk.

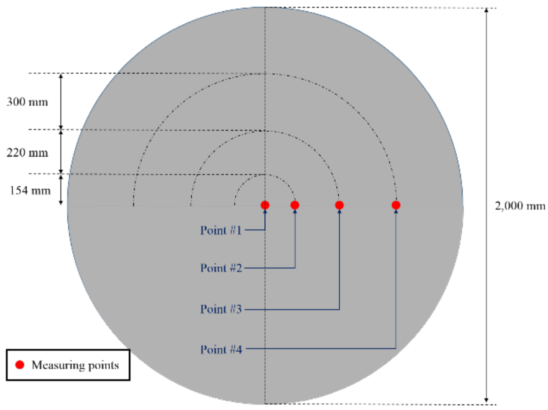

Fig. 3 Measuring points of target disk

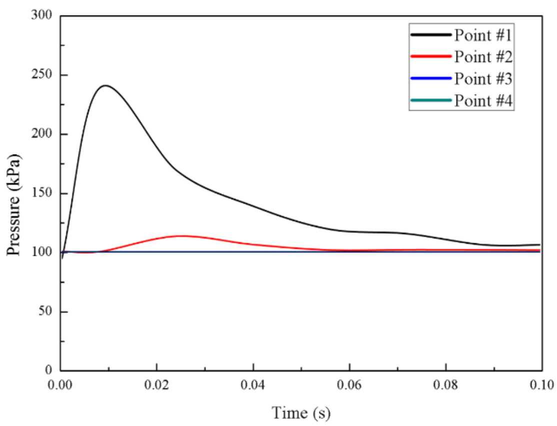

Fig. 4 Preliminary experimental results at target disk

3. Numerical Approach

3.1 Analysis Method

Coupled Eulerian-Lagrangian (CEL) technique has been widely used due to its effectiveness in modeling and large deformation analyses without re-meshing procedure. The technique is based on two-way coupling with Lagrangian and Eulerian methods at the intersection. TNT model which is commonly used as explosive material is applied to simulating the blast wave phenomenon and also employed with the CEL technique.

Especially, the well-known Jones-Wilkins-Lee equation of state (JWL EOS) was derived as follows [4]:

$$P(V,E) = A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega}{V}E \quad (1)$$

where P is the pressure caused by explosion, V is the relative volume as a ratio between explosive volume and initial volume (v/v_0) of explosive material. A, B, C, R_1, R_2 and ω are material constants which have independency on each other.

3.2 Preliminary Analysis Model and Conditions

Fig. 5 shows a three-dimensional numerical model of the experimental apparatus with 30,360 nodes and 26,870 elements. TNT and air model, where the blast wave is generated and transferred, were modeled by the Eulerian method and combined with the experimental apparatus modeled by Lagrangian method. And those are composed with 1,331 and 734,721 cells, respectively.

A boundary condition was applied to the air, it was opened to release high pressure produced by the blast wave and adopted as atmosphere pressure. Analysis time was set to be 10.0 msec which was decided by a previous study [4]. Material used in the analysis is stainless steel 400 which has 395 MPa of yield strength, 650 MPa of tensile strength, and 200 GPa of elastic modulus obtained from tensile test.

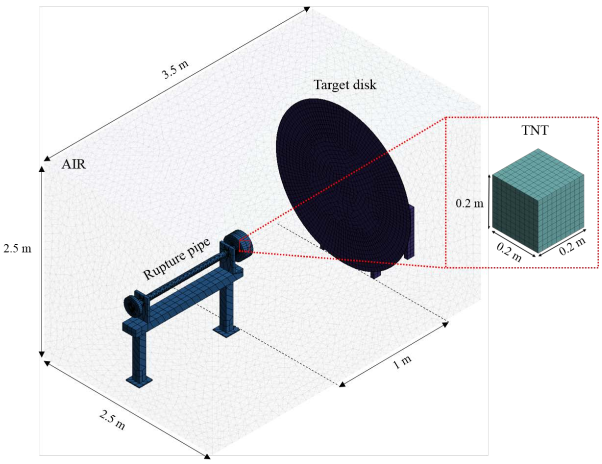

Fig. 5 Numerical model of experimental apparatus

3.3 Preliminary Analysis Results

Pressure distributions at Point #1 obtained from experiments and numerical analysis were investigated as shown in Fig. 4. The differences were consistent within 3.74 % of area. Based on the results, major parameters of JWL EOS which simulate the blast wave phenomenon under a preliminary HELB condition were derived in Table I. Main experiments and numerical analyses will be conducted to investigate the effects of rupture pressure, degree, and distance under HELB conditions.

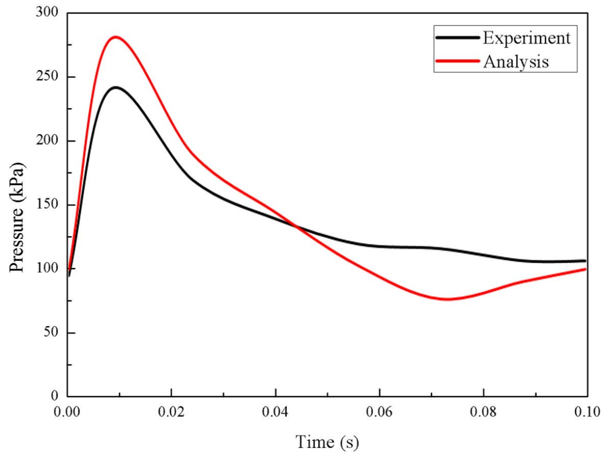

Fig. 4 Pressure distributions at Point #1

Table I: Major parameters of JWL EOS

A (GPa)	*B* (GPa)	*R₁*	*R₂*	*ω*	*ρ* (kg/m^3)	E_m (MJ/kg)
12.5	3.8	4.1	1.2	0.35	1,900	3.63

4. Conclusions

In this study, for the verification of major parameters of JWL EOS, preliminary analysis was conducted.

(1) Experimental apparatus has been set-up to demonstrate the blast wave under the HELB condition, and pressure distributions were obtained.
(2) Through the corresponding numerical analysis, major parameters were verified with experimental data.
(3) Further research accompanying main experiments will be conducted under HELB conditions.

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