Impulse load on the IRWST structure by the hydrogen detonation

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1. Introduction

According to the results of the hydrogen concentration distribution analysis for the APR1400 [1, 2], the hydrogen concentration in the IRWST is very high at some severe accidents sequences even though the igniter operates. From the calculation results [1], it would be possible for this high hydrogen concentration to sometimes cause the deflagration to detonation. Of course, there are lots of debates on the occurrence of a detonation in the IRWST because the IRWST has no obstacle that can cause the flame acceleration, also has no powerful ignition source for a direct detonation. In addition, there is low oxygen content and high steam content in the IRWST.

In this paper, the impulse load on IRWST structure is estimated using the TNT equivalent method in case of the occurrence of the hydrogen detonation in the IRWST. This method is used for the calculation of the detonation load for the containment in System 80+. The more details are described in the reference [3].

2. Methods and Results

The well-mixed atmosphere is assumed. There are two igniters in the IRWST in APR1400. The impulse load is estimated for the volume occupied by one igniter. The energy release from hydrogen detonation is 2.4E5 kJ/kg-mol. The atmospheric pressure of 29.7 psia and the temperature of 150F are assumed as the initial atmospheric condition. The theoretical explosive yield of TNT is 2.12MJ/lbm. So, the hydrogen mass equivalent to the TNT mass is obtained by dividing the released energy from detonation by the explosive yield from TNT. To get the actual impulse from the reference explosion impulse, three scaling laws of the distance, the time and the impulse are required.

2.1 Scaled distance

Applying the scaling principle to explosion, two explosions can be expected to give identical blast wave intensities at distance which are proportional to the cubic root of the respective energy release. The density of the atmosphere may be taken as a measure of the quantity of medium through which the explosive blast wave propagates. The reference explosion information at ~25 ft (7.62m) from the explosion for a point source load is used to assess the actual load. The reference TNT mass, W_o, is 2,000lbm. The explosive energy release can be mostly expressed in relative form of the energy released from some standard amount of a standard explosive. The energy release factor can so become a ratio $(W/W_o)^{1/3}$, where W is the energy release from the explosion. The atmospheric density term is also conveniently expressed relatively, becoming a dimensionless term $(\rho/\rho_o)^{1/3}$, where ρ is the density of the atmosphere through which the explosive shock has traveled and ρ_o that of the atmosphere for the reference explosive. Therefore, the scaled distance is obtained as

$$\text{scaled distance} = \frac{(\rho/\rho_o)^{1/3}(\text{actual disatnce})}{(W/W_o)^{1/3}} \qquad (1)$$

2.2 Scaled time

The scaling law for an explosion inherently contains the requirements for a scaled time as well as those for a scaled distance. As the required time scale is known, both arrival time and duration for some given explosion may be found by scaling up (or down) the corresponding values for the reference explosion. The principle of time scaling can be illustrated by considering arrival time. The scaled time is derived as

$$(\text{actual time}) = (\text{scaled time})\frac{(W/W_o)^{1/3}}{(\rho/\rho_o)^{1/3}(a/a_o)} \qquad (2)$$

where a/a_o represents a transmission factor for the speed of sound

2.3 Impulse scaling

Finally, a further characteristic of the explosion blast wave that may require scaling is its impulse per unit of area. The impulse is conveniently described in terms of the decay parameter. This parameter is an intensity-like variable that is treated as other intensity such as the Mach number or the peak overpressure ratio. That is, the decay parameter table or curves must be included in the proper- scaled distance. Knowing the decay characteristics of the blast wave (along with its peak overpressure and duration), the blast wave impulse (per unit of area) may be found as the time integral of the overpressure.

$$\text{Impulse} = \frac{1}{2}(P_{\text{refl}}\, t_{d,\text{actual}}) * \text{impluse factor} \qquad (3)$$

2.4 Results

Table 1 shows parameters for the case of the dry hydrogen presented in Table 2. Table 2 shows the impulse loads. The impulse load of the second column is the case considering dry hydrogen. The impulse load is calculated up to 30% hydrogen concentration where the maximum load due to hydrogen detonation occurs. The impulse increases with hydrogen concentration. The third column is the steam effect on the impulse load because it would be high steam fraction in IRWST from the gas concentration analysis. The impulse decreases with steam addition compared to that without steam. The fourth column shows the distance effect on the impulse load because distance from ignition point is important. In this case, the distance from the inner wall to the outer wall of the IRWST is considered. The impulse decreases with the distance from the ignition point. The design impulse load of the IRWST structure is not known, but we can predict the IRWST structure integrity due to hydrogen detonation using the previous available results. In our TROI test [4], we measured the dynamic pressure during steam explosion in the stainless steel interaction vessel. Fig. 1 shows the dynamic pressure due to the steam explosion. The stainless steel is 25mm) thick. The impulse load is 11.5MPaX0.25ms =0.42psi-sec. The stainless steel was not damaged due to this load. If IRWST thickness is greater than about 25mm, the integrity of the IRWST structure will be maintained for 13% hydrogen detonation with the steam faction.

Table1. Calculation parameters for the case without steam

H2 [%]	MH2 (kg)	Q XE6 (KJ)	W (lbm)	P_{refl} [psi]	t_d,, act [ms]	Impulse factor
13	7.7	0.921	435	423	5.2	0.558
15	8.9	1.062	501	461	5.5	0.537
20	11.8	1.417	668	595	6.4	0.485
30	17.7	2.125	1002	816	7.7	0.4

Table 2. Impulses for different initial conditions

H2 [%]	Impulse [psi-s]		
	Dry H2, Distance=15ft	20% Steam	Distance =22 ft
13	0.608	0.412	0.421
15	0.681	0.454	0.414
20	0.916	0.594	0.479
30	1.245	0.872	0.677

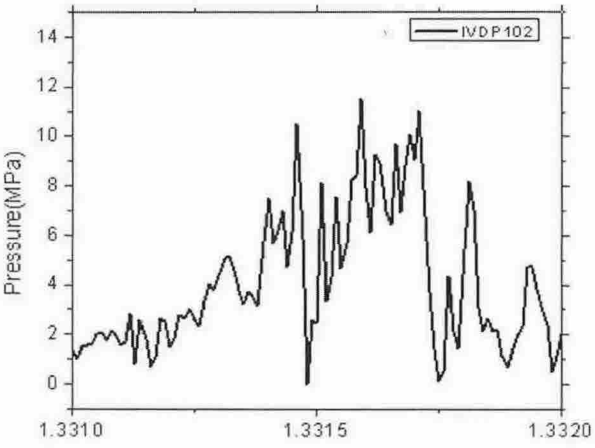

Fig. 1. Dynamic pressure in TROI test

3. Conclusion

The impulse load on the IRWST structure due to the hydrogen detonation is estimated using the simple TNT equivalent method. To estimate the integrity of IRWST structure due to hydrogen detonation, the impulse data on IRWST structure are required. Also, it is recommended that the impulse load for IRWST structure will be performed using the detail detonation analysis code.

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