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Methodology of Hydrogen Gas Jet/Plume Modeling and Calculate Hydrogen Detonable Mass for NPP Risk Assessment

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1. Introduction

When installing a hydrogen production facility to NPP, the impact of a hydrogen explosion on NPP safety must be considered. To assess the impact of a hydrogen explosion, it is necessary to determine the hydrogen detonable mass. For calculating the hydrogen detonable mass, it is assumed that a guillotine break accident occurs in the pipeline connected to the hydrogen production equipment or hydrogen buffer tank. In the event of a guillotine break accident in a pipeline connected to a high-pressure hydrogen storage tank, hydrogen gas will be released in a choked flow and will form a jet/plume. After modeling the hydrogen gas jet/plume, the detonable mass is determined using this model. In this model, hydrogen detonable mass is calculated by integrating over the predefined explosion region.

2. Methodology

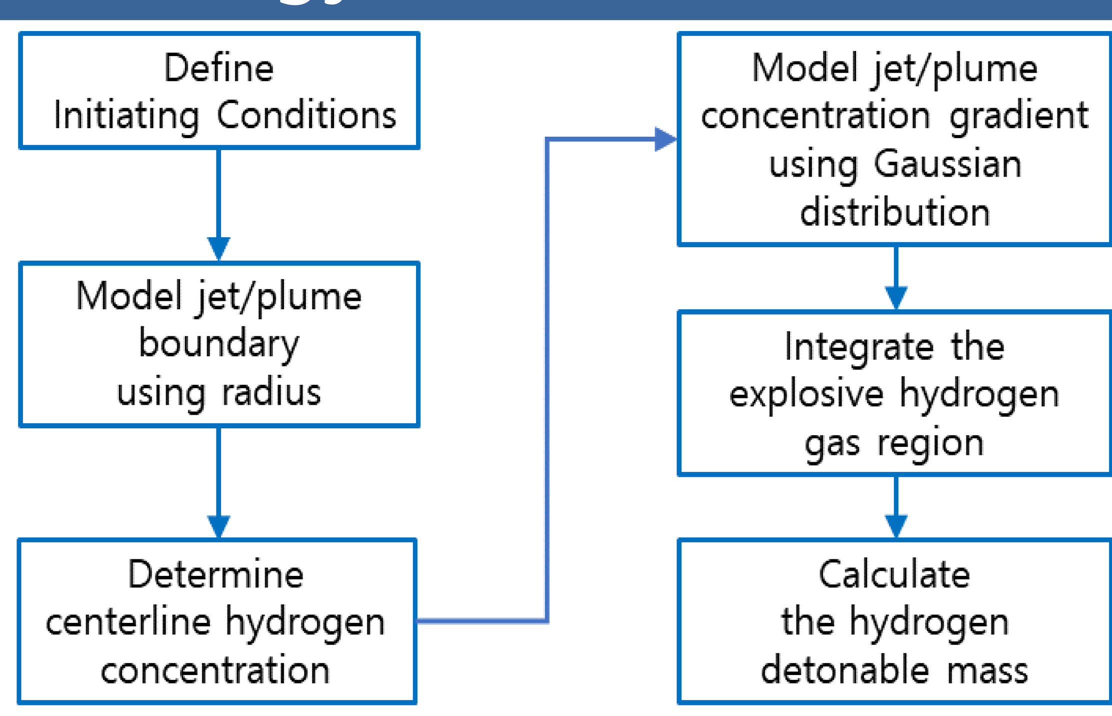

Fig 1. Procedure for modeling hydrogen jet/plume and calculate hydrogen detonable mass

2.1 Initial assumptions

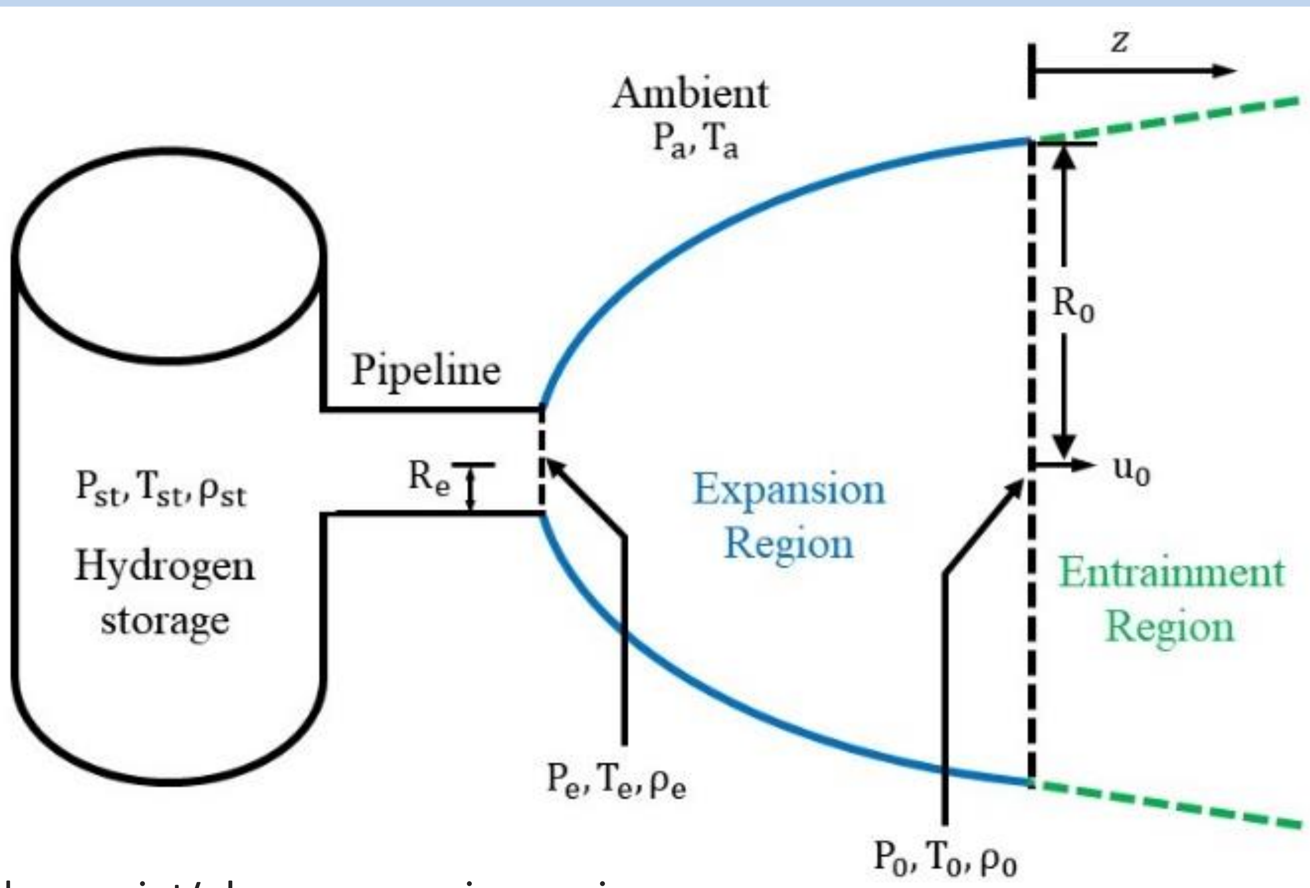

Fig 2. Hydrogen jet/plume expansion region

2.2 Determine hydrogen jet/plume boundary & centerline concentration

(1) $u_0 = \frac{G}{\rho_e} + \frac{P_e - P_a}{G}$

(2) $R_0 = R_e \left(\frac{G}{u_0 \rho_0}\right)^{0.5}$

(3) $R = \frac{R_0}{Y}\sqrt{\frac{T_a}{T_0}\left[Y + \frac{M_{H_2}}{M_{air}}(1-Y)\right]}$

(4) $Y_{cl} = \left[1 + \frac{2E_0}{R_0}\left(\frac{\rho_a}{\rho_0}\right)^{0.5} z\right]^{-1}$

(5) $y_{cl} = \left[1 + \left(\frac{1}{Y} - 1\right)\frac{M_{H_2}}{M_{air}}\right]^{-1}$

2.3 Using gaussian distribution for jet/plume dispersion

(6) $f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$

(7) $f_{max}(x) = \frac{1}{\sigma\sqrt{2\pi}}$

(8) $\alpha = \frac{y_{cl}}{f_{max}(x)}$

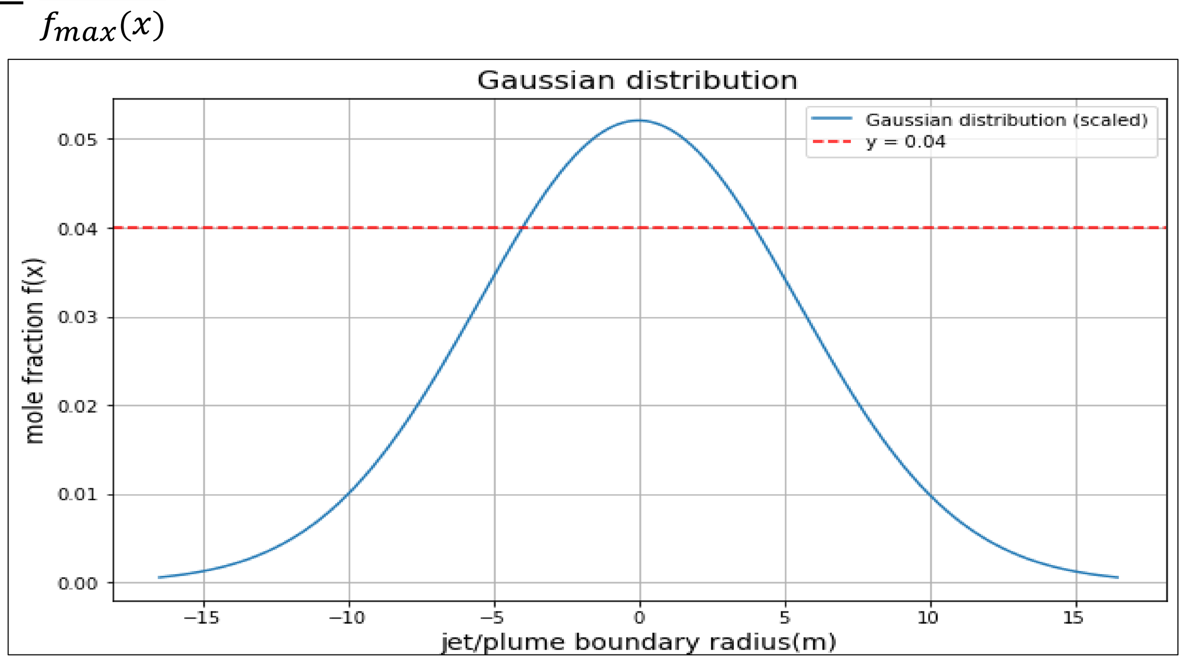

Fig 3. Gaussian distribution of the jet/plume radius at dispersion distance 100m

2.4 Determine hydrogen detonable mass

(9) $V_{jet} = \int_0^z \pi R^2 \, dz$

(10) $m_{jet} = \int_0^z \pi R^2 \rho Y \, dz$

(11) $\rho = \left[\frac{R_{id} T_a}{P_a}\left(\frac{Y}{M_{H_2}} + \frac{1-Y}{M_{air}}\right)\right]^{-1}$

(12) $m_{det} = \int_0^{z_{LDL}} \pi R^2 \rho Y \, dz - \int_0^{z_{UDL}} \pi R^2 \rho Y \, dz$

3. Modeling Results

Table I. Modeling initial conditions

Symbol	variable	initial data
P_{st}(Pa)	Storage pressure	7.00E+06
T_{st}(K)	Storage temperature	293
T_a (K)	Ambient temperature	293
R_e (m)	Pipeline radius	0.05

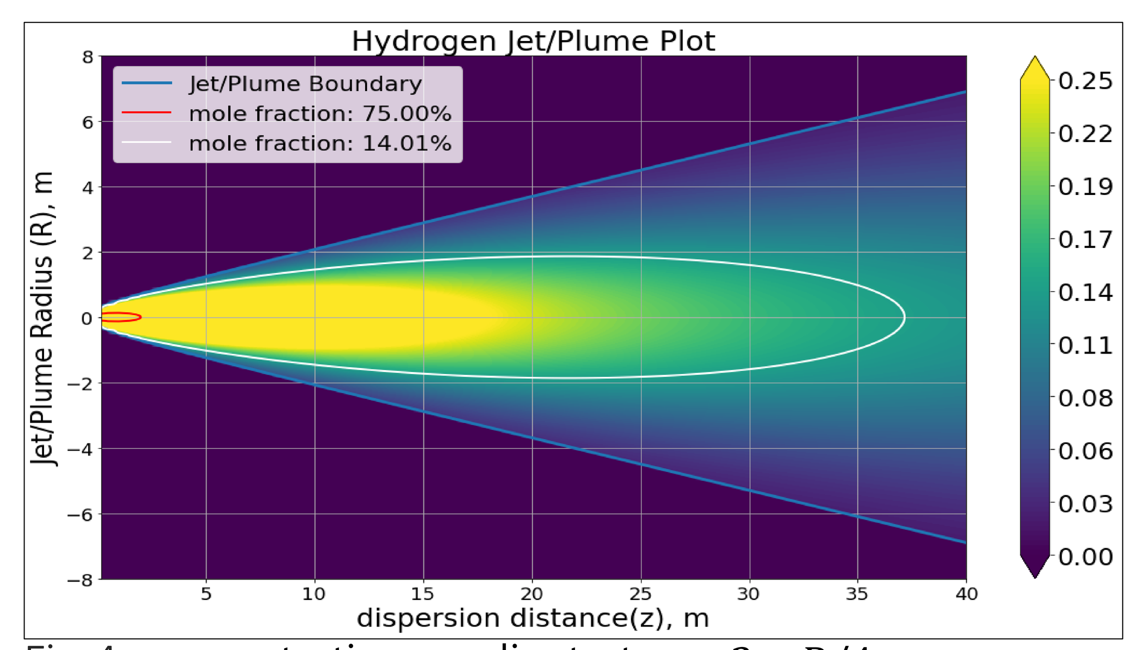

Fig 4. concentration gradient at $\sigma = 2 \times R/4$

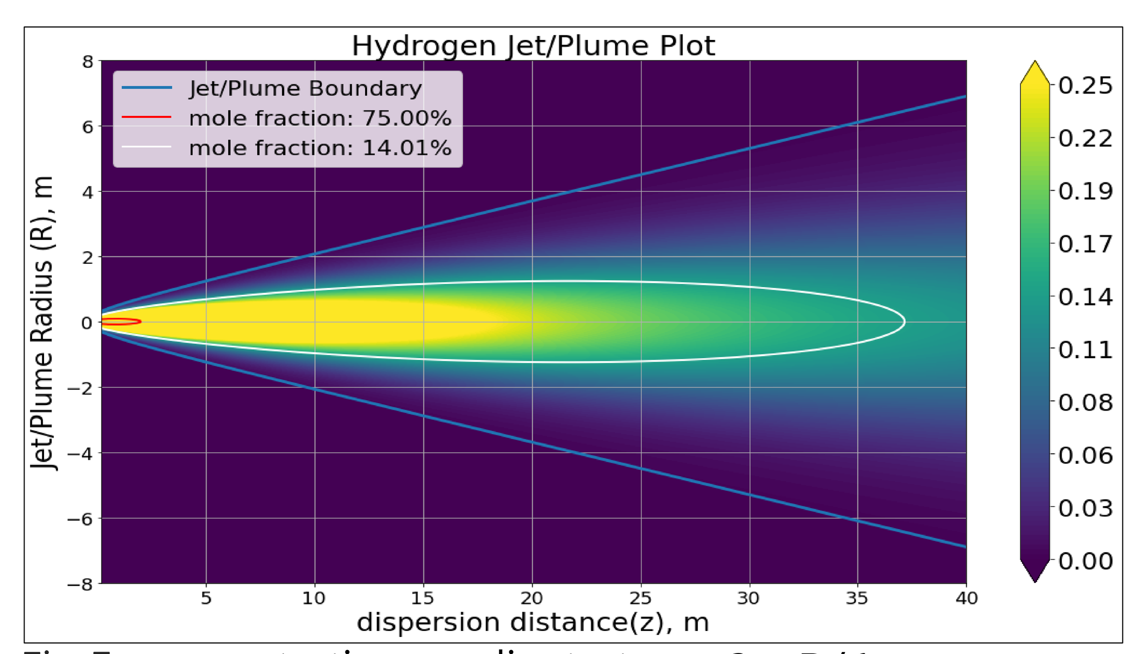

Fig 5. concentration gradient at $\sigma = 2 \times R/6$

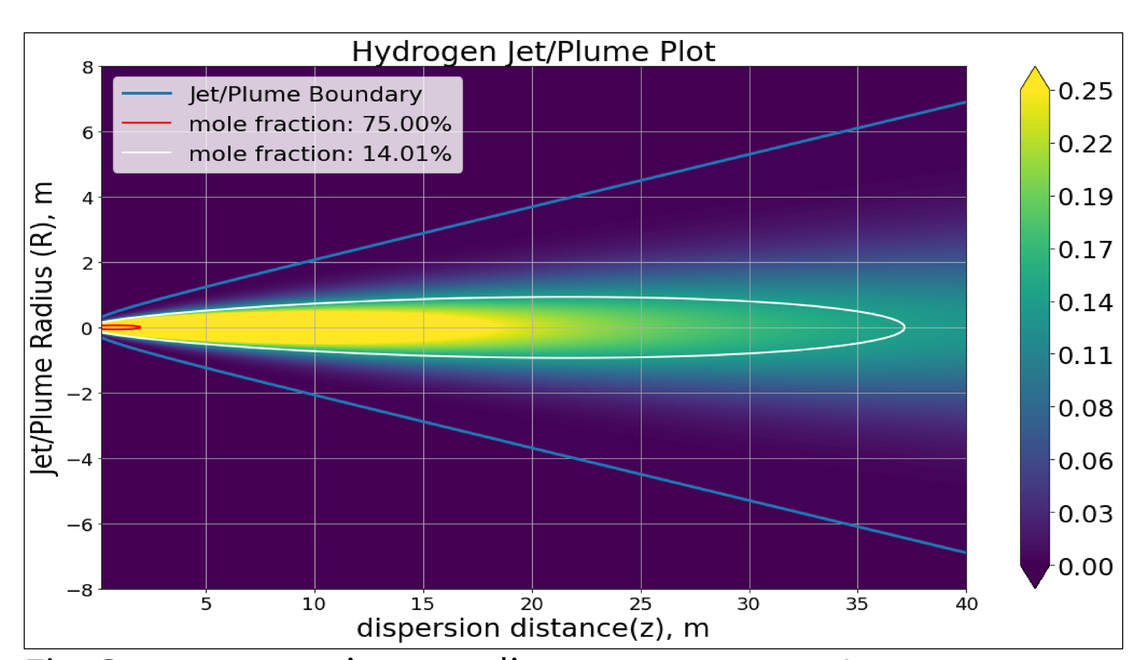

Fig 6. concentration gradient at $\sigma = 2 \times R/8$

Table II. Hydrogen detonable mass

standard deviation (σ)	detonable mass(kg)
$2 \times R/4$	5.65
$2 \times R/6$	2.51
$2 \times R/8$	1.41

4. Conclusions

To evaluate the impact of NPP accidents caused by hydrogen explosions from hydrogen production facility, an analysis of the hydrogen detonable mass was conducted. The mass analysis involved modeling the boundaries of the jet/plume of leaking hydrogen based on the initial temperature and pressure conditions of a hydrogen storage tank. A Gaussian distribution was applied to the modeled hydrogen jet/plume to model the contours according to hydrogen concentration. Using this model, the hydrogen detonable mass was calculated. The hydrogen detonable mass can vary depending on the standard deviation setting of the Gaussian distribution. Therefore, it is important to set the standard deviation correctly to determine the hydrogen detonable mass. By appropriately setting the standard deviation based on experimental data or technical guidelines, the hydrogen detonable mass within the hydrogen jet/plume can be determined. Using the calculated hydrogen detonable mass, overpressure calculations can be performed to assess the safety impact on the NPP.