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# Dispersion Analysis of Hydrogen in the Atmosphere According to Release Rate and Wind Speed

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## 1. Introduction

Recently, as hydrogen energy has been in the spotlight, hydrogen production using nuclear energy is drawing great attention. However, since hydrogen is a flammable material, safety concerns must be resolved when hydrogen production facilities are placed near nuclear power plants. That is, even if an explosion occurs due to the leakage of hydrogen at the hydrogen production facility, the impact of the accident should not impair the safety of the nuclear power plant. Hydrogen is transported and dispersed along the wind after it leaks. If the concentration is within the flammable limit, and an ignition source exists, a hydrogen explosion occurs. Therefore, it is important to predict the location of the explosion in order to accurately interpret the impact of the nuclear power plant due to the hydrogen explosion. Therefore, in this study, the dispersion of hydrogen gas is analyzed by applying the Gaussian plume model which is used to estimate radiological consequence after accident. In addition, concentration distribution on the ground was analyzed with the release rate of hydrogen and wind speed, which are important variables for dispersion analysis.

## 2. Hydrogen Explosion

Hydrogen is the one of the flammable materials, which is light, has a wide flammable range, a terrifying effect of an explosion, and small minimum ignition energy. Hydrogen diffuses through the air much faster than other materials as it is the lightest material in the earth. Also, it can be ignited with a very small amount of energy. After ignited, the flame propagates very quickly, leading to an explosion. The amount of energy released by the explosion is so great that a hydrogen explosion can cause significant damage. Therefore, it is necessary to understand the characteristics of hydrogen explosion and evaluate the effects of the hydrogen explosion.

The worst-case scenario for hydrogen releases into atmospheric conditions is the detonation of a hydrogen-air vapor cloud explosion. A vapor cloud explosion is a phenomenon in which a large amount of flammable vapor is released, dispersed, mixed with air, and then ignited and exploded. When a vapor cloud explosion occurs, a shock wave is generated, resulting in an overpressure of up to 14 times the atmospheric pressure [1]. Even if the shock wave caused by the detonation generated near the hydrogen production facility is propagated in the direction of the nuclear power plant, the nuclear power plant should be maintained in safe from the effect. In other words, hydrogen production facilities must secure a separation distance that guarantees the safety of nuclear power plants. When estimating the separation distance, it is important to predict the explosion point. The explosion point is determined by the location of the ignition source and whether the concentration at that location is within the flammable limit. Therefore, it is necessary to predict the concentration according to the distance through dispersion analysis, and to reflect it in the determination of the explosion point to predict the impact of the explosion.

## 3. Gas Dispersion

3.1 Gaussian Plume model

In this study, the hydrogen concentration according to the distance was calculated with the parameters affecting the dispersion. Assuming that the ignition source always exists everywhere, the hydrogen gas concentration on the ground was evaluated. Dispersion Parameters include material quantity or leak rate, wind speed, atmospheric stability, ground conditions, and leak height [2]. The dispersion analysis was performed by Gaussian plume model. The Gaussian plume model is used to predict the steady-state concentration of a leaking material from a continuous leak source. In this study, the concentration at the ground is predicted, and long-distance analysis beyond the flammable limit of hydrogen is not dealt with. In the equation (1), $C(x,y,z)$ is a concentration of hydrogen in air at $(x,y,z)$. $\dot{Q}$ is a leakage rate, $u$ is wind speed, $H_E$ is an effective leakage height, $H_M$ is a mixture leakage height and $\sigma_y$, $\sigma_z$ are variance coefficients with y-axis, z-axis.

$$
\begin{aligned}
C(x,y,z) = {} & \frac{\dot{Q}}{2\pi\sigma_y\sigma_z u} exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \\
& \times \left\{ exp\left[-0.5\left(\frac{H_E - z}{\sigma_z}\right)^2\right] + exp\left[-0.5\left(\frac{H_E + z}{\sigma_z}\right)^2\right] \right. \\
& + \sum_{i=1}^{N} \left\{ exp\left[-0.5\left(\frac{2iH_M + H_E - z}{\sigma_z}\right)^2\right] \right. \\
& + exp\left[-0.5\left(\frac{2iH_M - H_E - z}{\sigma_z}\right)^2\right] \\
& + exp\left[-0.5\left(\frac{2iH_M - H_E + z}{\sigma_z}\right)^2\right] \\
& \left.\left. + exp\left[-0.5\left(\frac{2iH_M + H_E + z}{\sigma_z}\right)^2\right] \right\} \right\}
\end{aligned}
\tag{1}
$$

3.2 Atmospheric conditions

The atmospheric conditions are important parameters for dispersion analysis because it determines the variance coefficient. The conservative maximum concentration may be estimated by assuming the atmospheric stability that result minimum values of the variance coefficients and slower wind speed. In other words, as the wind speed decreases and atmospheric stability comes from A to F, the more conservative the assumption becomes. Figure 1 and 2 means that the degree of dispersion decreases as the atmospheric stability comes from A to F. In this study, it is assumed that the atmospheric stability is F and wind speed is 1.5m/s [3]. In addition, the leakage point was assumed the ground level. The atmospheric temperature is 40°C and the temperature of the released gas was assumed to be the equal to the atmospheric temperature.

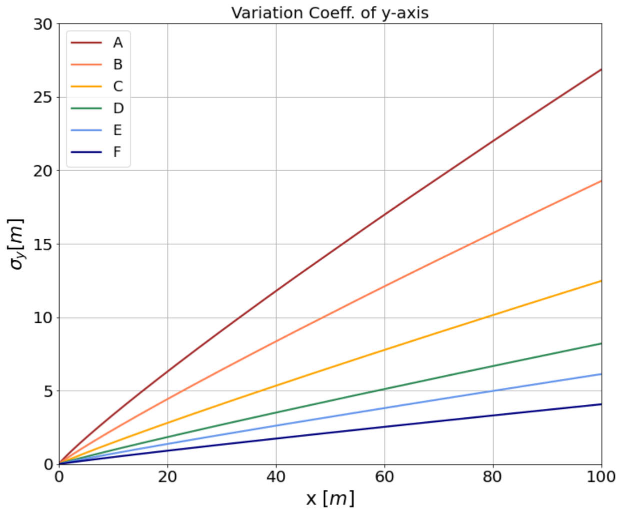


Figure 1 The variation coefficient of y-axis ($\sigma_y$) with the distance from the leakage point according to atmospheric stability

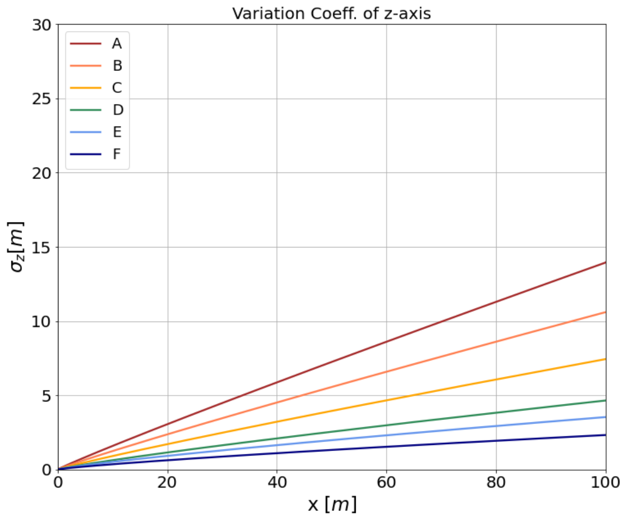


Figure 2 The variation coefficient of z-axis ($\sigma_z$) with the distance from the leakage point according to atmospheric stability

## 4. Analysis Results

In this study, the maximum concentration distribution according to the distance from the leakage point was predicted when the release rate of hydrogen is 0.5m$^3$/s and 1.0 m$^3$/s. Figure 3 shows the maximum concentration with the distance from the leakage. The maximum concentration means the concentration at the plume center and on the ground. The flammable limit of hydrogen is from 40,000 to 756,000ppm. When the release rate is 0.5m$^3$/s and 1.0m$^3$/s, the maximum concentration drops below the lower explosive limit when it is at least 51m and 76m away from the leakage point.

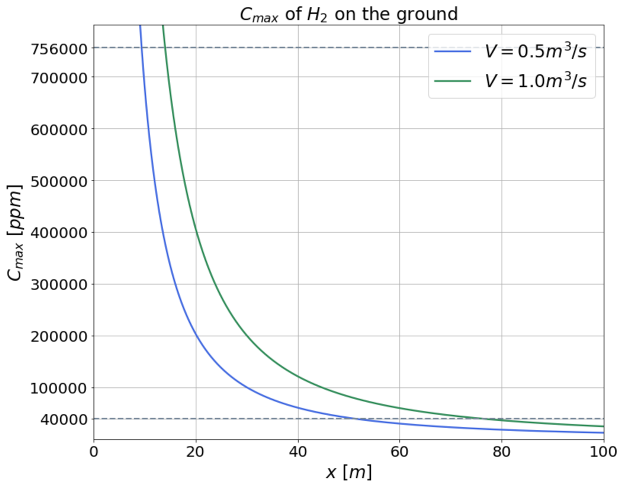


Figure 3 The maximum concentration of hydrogen with the distance from the leakage point

Figure 4 and 5 are the contours for the cases analyzed above. As the release rate, the concentration distribution on the ground becomes widen.

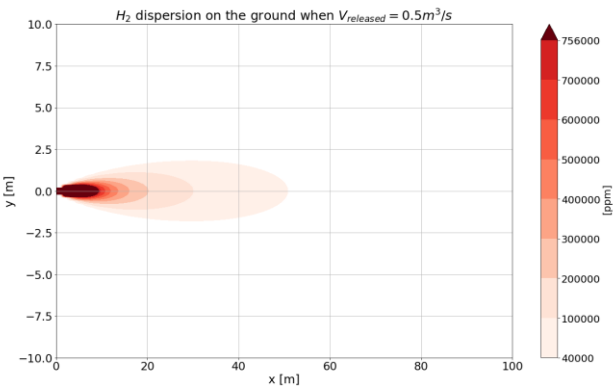


Figure 4 The concentration distribution with the distance from the leakage point when 0.5m$^3$/s of release rate

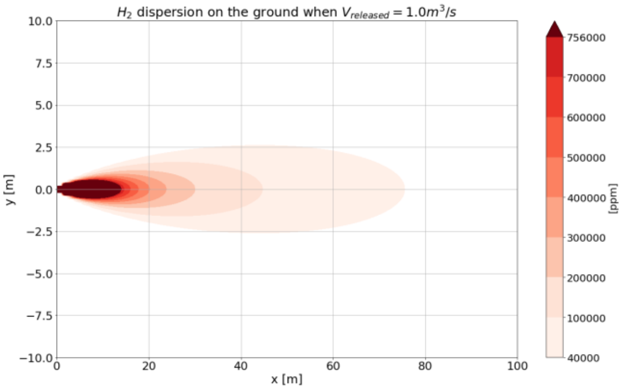


Figure 5 The concentration distribution with the distance from the leakage point when $1.0m^3/s$ of release rate

## 5. Conclusion

In order for a hydrogen production facility to be deployed near a nuclear power plant, the effect of a hydrogen explosion may not significantly affect the safety of the nuclear power plant. In the worst-case scenario, assuming a hydrogen explosion, a shock wave is generated, and even if this shock wave is propagated, a separation distance sufficient to not cause significant damage to the nuclear power plant is required. Since the pressure wave propagates from the leakage point, it is important to predict the explosion source when calculating the separation distance. The explosion source is determined by the location of the ignition source and concentration at that location. Therefore, in this paper, the dispersion of hydrogen gas from the leakage point was analyzed while varying release rate assuming the most conservative atmospheric conditions. It is assumed that atmospheric condition is F and wind speed is 1.5m/s. As shown result, an additional separation distance that falls below the flammable limit may be needed. That is, when designing a hydrogen production facility, an ignition source should be excluded as much as possible within the distance. In addition, dispersion analysis should be reflected when calculating the separation distance. In the dispersion analysis, the atmospheric stability, wind speed and release rate are the critical variables, so care may be taken when assuming this.

## REFERENCES

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