Effects of diffusion-coefficient models on atmospheric dispersion factors at different release levels

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1. Introduction

During normal operation of the nuclear power plants (NPP), radioactive gaseous effluent is released to the atmosphere. After diffusing, this effluent exerts radiological effects on environment and people nearby. Evaluation of the environmental impact by the effluent is required for the construction permit and operation license of NPP. Gaussian plume model is one of the most popular choices in analyzing atmospheric dispersion of gaseous effluents. The atmospheric dispersion is estimated in terms of the atmospheric dispersion factor χ/Q, which is defined as the ratio of the radioactivity concentration χ in air to the activity release rate Q from a source stack. The spatial variations of dispersion factor are reflected by dispersion coefficients. In this study, we investigated the influence of diffusion coefficients of choice on the downwind distribution of dispersion factor

2. Theory

The Gaussian plume model is expressed in a simple mathematical form, which enables easy preparation of input data and quick computation. The following function expresses the Gaussian plume model for dispersion factor χ/Q at a location (x, y, z) with the gas release at (0, 0, H). $\bar{u}$ is wind speed and $\sigma_y(x)$ and $\sigma_z(x)$ are the horizontal and vertical diffusion coefficients respectively, at a downwind distance x.

$$\frac{\chi(x,y,z)}{Q} = \frac{1}{2\pi\bar{u}\sigma_y(x)\sigma_z(x)} \times \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y(x)}\right)^2\right] \times \left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z(x)}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z(x)}\right)^2\right]\right\} \quad (1)$$

Integrating the equation (1) with respect to y over $-\infty < y < \infty$ leads to the following function for the dispersion factor at the ground level:

$$\frac{\bar{\chi}(x)}{Q} = 2.032 \times \sum_{i\,j} \frac{f_{ij}}{\sigma_{zj}(x)\bar{u}_i x} \times \exp\left[-\frac{1}{2}\left(\frac{h_e}{\sigma_{zj}(x)}\right)^2\right] \quad (2)$$

where h_e is the effective height (H + plume rise) and f_{ij} is the frequency of i_{th} wind speed class and j_{th} stability class is observed. In the case of ground level release, the function has a simpler form with the vertical diffusion coefficient $\Sigma_z(x)$ modified considering building effect.

$$\frac{\bar{\chi}(x)}{Q} = 2.032 \times \sum_{i\,j} \frac{1}{\Sigma_{zj}(x)\bar{u}_i x} \quad (3)$$

3. Materials and Methods

3.1 Meteorological Data

Recent two years (2017-2018) of meteorological data at Kori NPP site were provided by Korea Hydro & Nuclear Power (KHNP). Data inform the meteorological conditions monitored at 58 m from the ground.

The windrose in Figure 1 summarizes the percentages of wind speed and direction. North is the most frequent windward and south-southeast (SSE) is the least frequent windward.

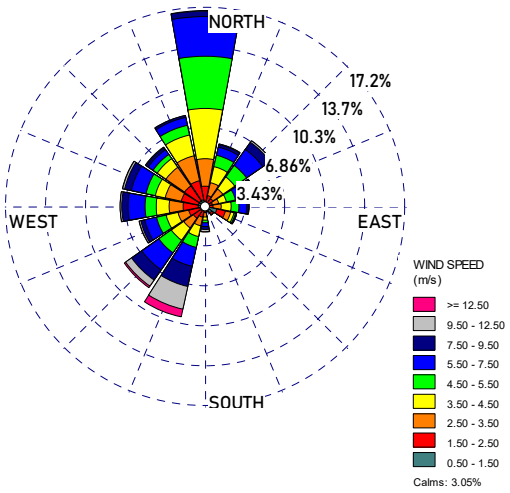

Figure 1. Windrose for Kori NPP site over the years 2017 and 2018

3.2 Diffusion Coefficients

Diffusion coefficients $\sigma_y(x)$ and $\sigma_z(x)$ in equation (1) are highly dependent on the atmospheric stability. Briggs [1], Eimutis-Konicek [2], Klug [3] and Hosker [4] suggested different mathematical models to calculate diffusion coefficients for 6 stability conditions classified by the Pasquill-Gifford-Turner scheme [5]. With the frequency data of atmospheric stability at Kori NPP site, four different packages of diffusion coefficients were prepared.

3.3 Calculation of atmospheric dispersion factors

Dispersion factors were calculated for each of 16 wind direction sectors with the data for 10 wind speed classes. In case of ground release (H = 0), the vertical diffusion coefficients were calculated considering the building

wake correction [6] by equation (4) to be applied to equation (3):

$$\Sigma_z(x) = (\sigma_z^2(x) + 0.5D_z^2/\pi)^{\frac{1}{2}} \leq \sqrt{3}\sigma_z(x), \quad (4)$$

where D_z is the maximum adjacent building height.

For the elevated level release (H = 120), the following Briggs Plume rise [7] was applied to equation (2):

$$h_{pr} = 1.44(\frac{W_0}{\bar{u}})^{\frac{2}{3}}(\frac{X}{d})^{\frac{1}{3}} \cdot \mathrm{d} \quad (5)$$

where W_0 is the stack release velocity and d is internal stack diameter. If W_0 is less than 1.5 times the wind speed $\bar{u}$, a correction for downwash equation (6) is subtracted from equation (5).

$$\mathrm{C} = 3\left(1.5 - \frac{W_0}{\bar{u}}\right)d \quad (6)$$

4. Results

4.1 Ground release

Figure 2 presents dispersion factors along the SE section, where the χ/Q values were highest, obtained by employing four different diffusion coefficient data. The χ/Q value decreases with the downwind distance regardless of the model for diffusion coefficient. The highest χ/Q values came with the Hosker's diffusion coefficients whereas the lowest values resulted from the Eimutis's diffusion coefficients. The χ/Q values based on four different models for diffusion coefficient are compared in Table 1.

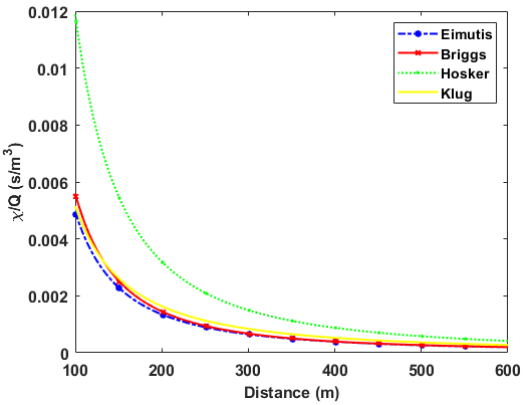

Figure 2. Atmospheric dispersion factors varying with the downwind distance in the SE direction at the ground level release: D_z = 67.5 m

Table 1. Atmospheric dispersion factors χ/Q along the downwind distance at the ground level release: D_z = 67.5 m

Distance (m)	Eimutis	briggs	Hosker	Klug
300	6.48E-04	6.74E-04	1.50E-03	8.41E-04
400	3.89E-04	3.95E-04	8.78E-04	5.26E-04
500	2.62E-04	2.70E-04	5.81E-04	3.66E-04
700	1.52E-04	1.53E-04	3.14E-04	2.13E-04

4.2 Elevated release

Regardless of the model for diffusion coefficients, the maximum χ/Q values were obtained in S direction. From the release spot, the χ/Q value increased along the downwind distance until reaching the peak value and then decreased. The distance of peak value and the slope of change in χ/Q varied depending on the model for diffusion coefficient. With the coefficients produced by the Eimutis-Konicek model, the peak value was the highest at the shortest distance. The lowest peak value at the farthest distance was attributed to the diffusion coefficients produced by the Hosker's model. The peak values of χ/Q and the distances based on four different models for diffusion coefficient are listed in Table 2.

Table 2. The peak values of χ/Q and the distances at the elevated release: W_0 = 10 m/s and d = 2 m

	Eimutis	briggs	Hosker	Klug
Distance (m)	516	685	781	627
χ/Q (s/m^3)	1.41E-06	9.40E-07	8.23E-07	1.08E-06

5. Conclusion

Meteorological condition regarding wind speed, wind direction and atmospheric stability determines the atmospheric dispersion of gaseous effluents. In theoretical analysis of the atmospheric dispersion with the Gaussian plume model, the key factors are the diffusion coefficients. Hence, the mathematical model employed to calculate the diffusion coefficients practically determines the pattern of dispersion factor varying with the downwind distance. With Eimutis-Konicek's model, the atmospheric stability class A was most influential on the pattern of dispersion factor varying along the downwind distance. With Hosker's model, the stability classes D was more influential than others on the distribution pattern of dispersion factor.

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