1. Physical model experiment (wind tunnel experiment case)

Wind tunnel experiment is one of the proven methods for the estimation of atmospheric diffusion. The **topography/ buildings models** are set up into a **wind tunnel**, and the observations of air current and diffusion of tracers are performed under the temperature/ wind speed control. For the tracer gases, such as ethylene, propane are used. Model scales are 1/100 ~ 1/5000 in general, and the experiments must satisfy the **rule of similarity**.

When applying the physical models to the estimation of the diffusion in the real world, some parameter(s) should have coincident value between the model and the field observations. Typical rules are:

- **similarity of the air current**

  having the coincident value on the **turbulent Reynolds number** Re_t defined as,

  $Re_t = UL/K$,

  where, U: wind speed [m/s], L: representative length [m], and K: eddy viscosity [m^2/s].

- **similarity of the diffusion**

  having the coincidence on the diffusion such as the concentration width of gas (σ_y: standard deviation in the crosswind direction of the plume concentration distribution).

- **similarity of the thermal effect**

  having the coincident value on the **bulk Richardson number** Ri_b defined as,

  $Ri_b = gL\Delta T/ TU^2$,

  where, g: gravity acceleration [m^2/s], L: representative length [m], ΔT: temperature difference [℃], T: temperature [℃], U: wind speed [m/s]. This equation is the same one of the Ri number definition in which temperature/ wind speed gradient are converted to the bulk values.

2. Numerical model

a. diffusion equation

For the calculation of distribution of pollutants, we need **two steps of model** calculations, the equation of **emission height** and the equation of **diffusion**. The **stack gas** rises with the energy of gas emission speed initially, and continues to rise with the energy of heated gas buoyancy. Some number of equations for the estimation of plume rising was proposed such as,

•rise of the plume - CONCAWE equation

The equation was given by an atmospheric environmental research project, CONCAWE, and rise of stack gas **Δh** from the top of stack is estimated as,

$\Delta h = a\, Q_H^{\alpha}\, U^{-\beta}$

where, Q_H : emission heat capacity [cal /s], U: wind speed [m], a, α, and β are constant for each value is, 0.175, 0.5, 0.75.

•rise of the plume - Briggs equation

The equation proposed by Briggs (1969) in U.S. EPA as,

$\Delta h = 3\, v_g D / U$ (in the case of windy)

$\Delta h = 1.4 Q_H^{1/4} (d\theta / dz)^{-3/8}$ (in the case of **wind speed is 0**)

where, v_g : emission speed [m/s], D :stack output diameter [m].

•Effective stack height

The effective stack height H_e is defined as,

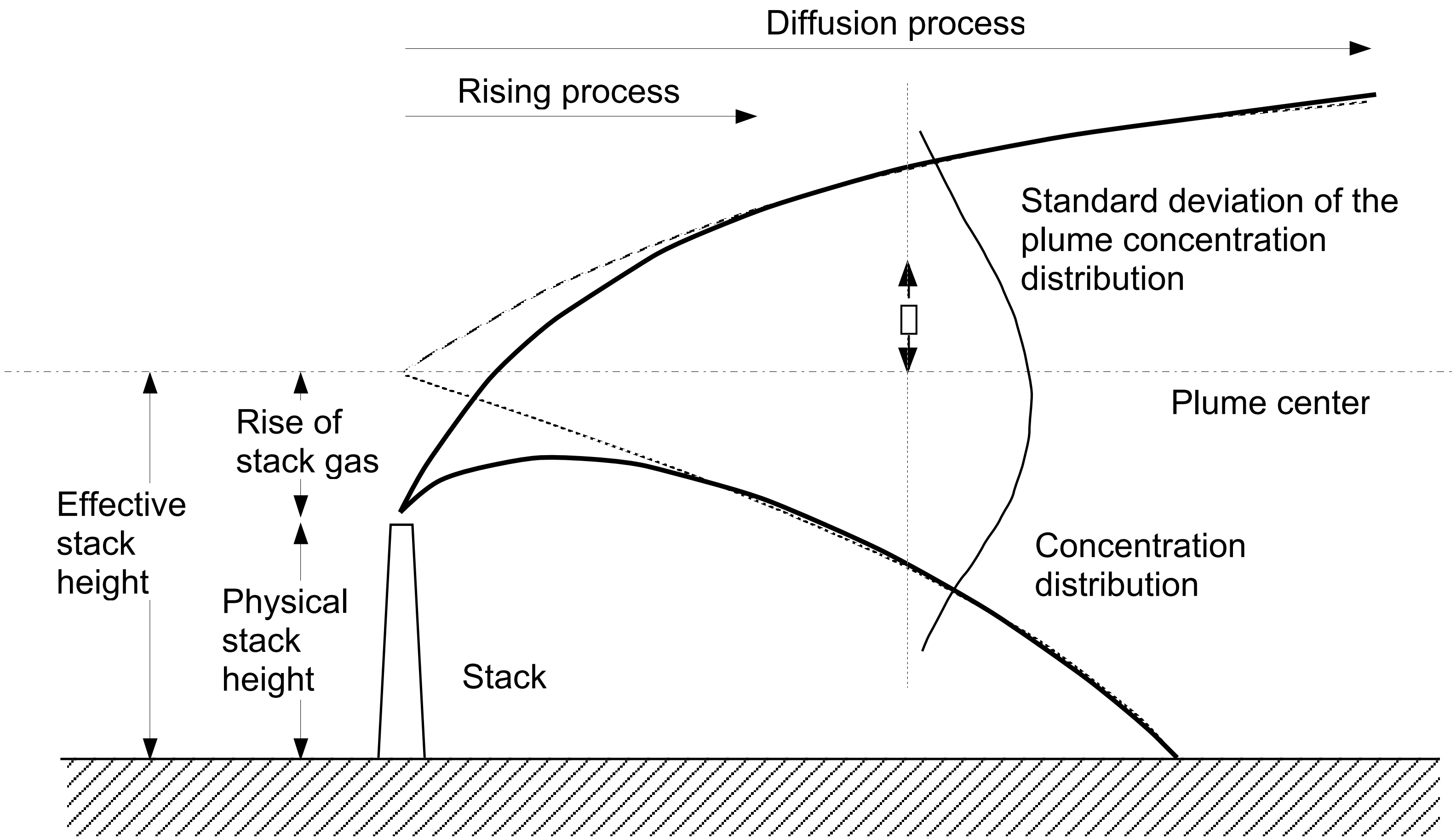
$H_e = H_0 + \Delta h$,

where, H_0 is the physical stack height.

b. plume model

•plume dispersion

We can assume the plume is released from the pseudo-emission point of which height is He as follows,



•**Diffusion equation**

When the wind direction, speed, diffusion coefficients are in steady condition, we can obtain the **normal distribution type atmospheric diffusion equation** defined as,

$$C(x, y, z) = \frac{Q}{2\pi U \sigma_x \sigma_y} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left\{ \exp\left[-\frac{(z - H_e)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z + H_e)^2}{2\sigma_z^2}\right] \right\},$$

where,

C(x, y, z) denotes the concentration (unit for the gaseous pollutants is [m^3/m^3],
unit for the particulate pollutants is [g/ m^3], and unit for the radioactive matter is [Bq/ m^3]),

Q : emission rate of a source (unit for the gaseous pollutants is [m^3N/ s],
unit for the particulous pollutants is [g/ s], and unit for the radioactive matter is [Bq/ s]),

U : wind speed [m/s],

σ_y, σ_z : standard deviation of a plume concentration distribution for y and z [m],

H_e : effective stack height [m].

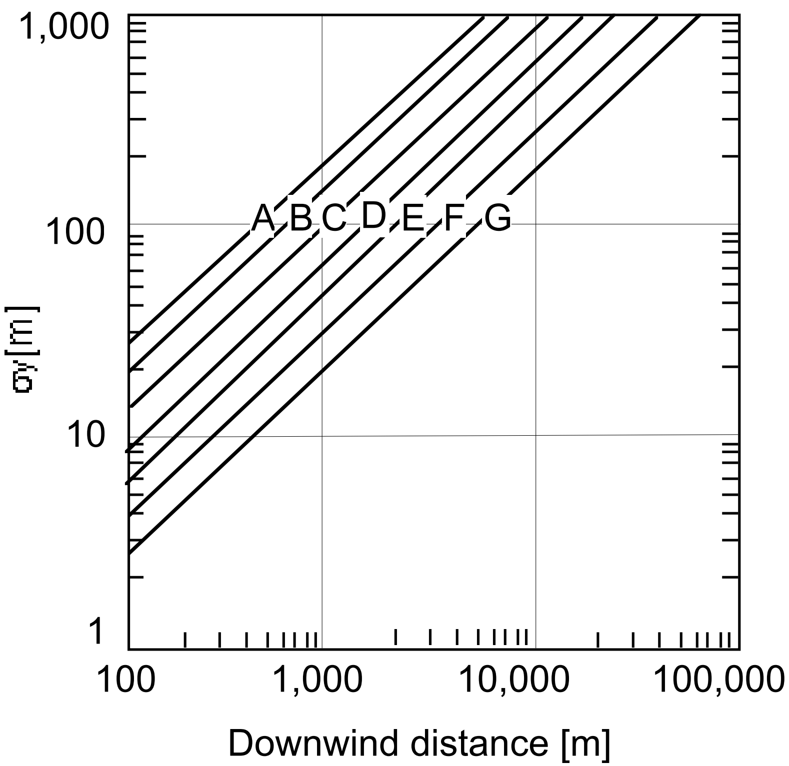
In the case of long term, for example 1 year, estimation, the better result is given considering that the y-directional concentration is homogeneous in the one wind direction of 16 divided wind rose as,

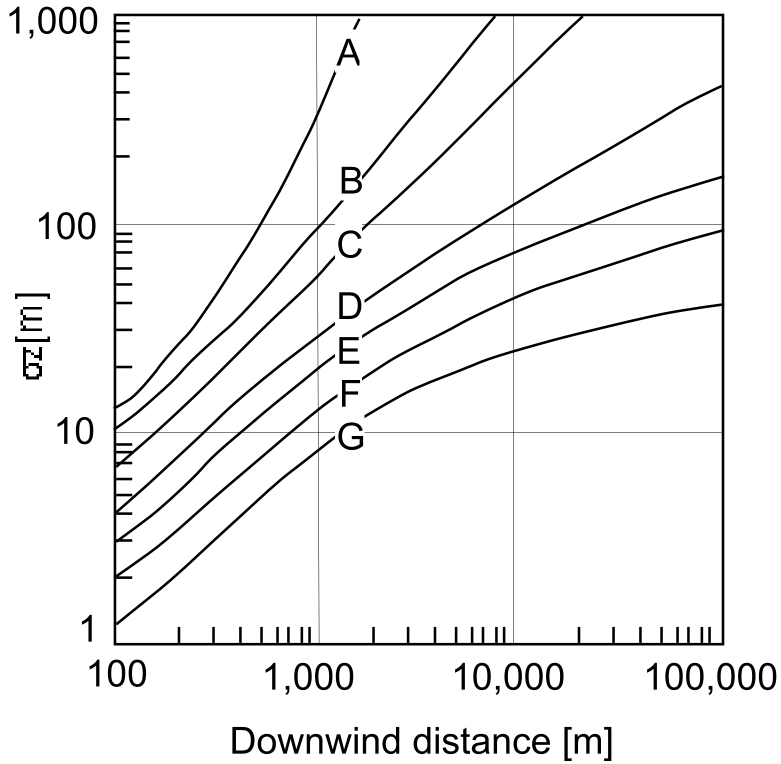
$$C(x, z) = \sqrt{\frac{1}{2\pi}} \frac{Q}{\frac{\pi}{8} R U \sigma_z} \left\{ \exp\left[-\frac{(z - H_e)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z + H_e)^2}{2\sigma_z^2}\right] \right\},$$

where R denotes the distance between the emission point and the evaluating point [m].

•Plume dispersion parameter

The above mentioned diffusion equation requires the parameter of plume dispersion, σ_y, σ_z , to calculate the concentration. Tailor (1921) studied theoretically on the dispersion, Sutton (1947), Pasquill (1961), and Briggs (1973) followed and gave the parameters. Gifford (1961) gave the parameters using Pasquill stability table called **Pasquill-Gifford chart**.



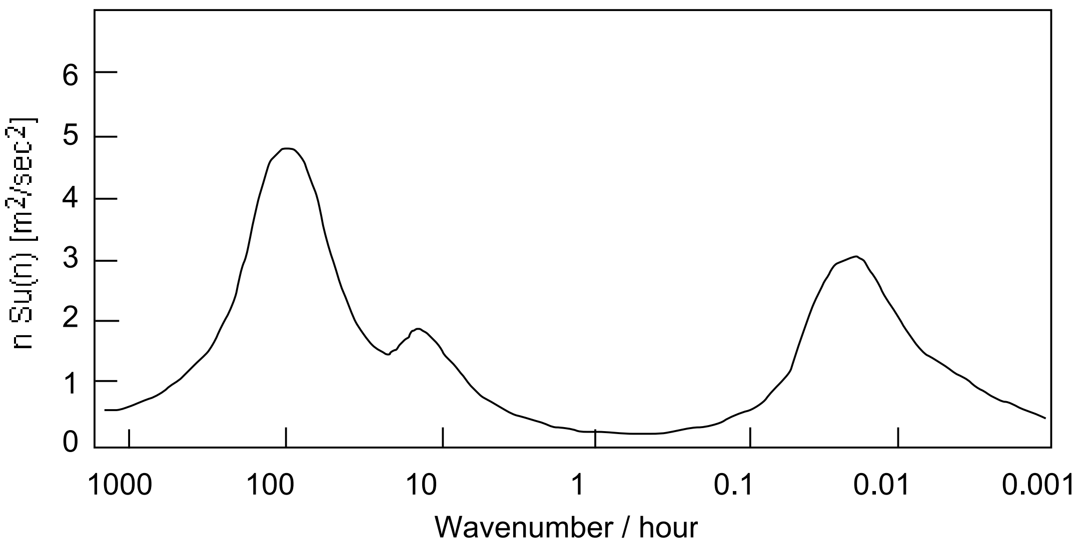


- **Concentration dilution and evaluation time**

There are various size of the turbulences in the atmosphere, then, the gas dispersion is relating the size of the turbulence. The horizontal dispersion size increases with prolonging the evaluation time, and the concentration decrease on the contrary. Then the concentration calculation must consider the **evaluation time length**. The Pasquill-Gifford chart can be used for the evaluation time of 3 minutes. The compensation equation for the longer evaluation time is given as,

$\sigma_{yt} / \sigma_{yt0} = (t / t_0)^p$,

where, σ_{yt} , σ_{yt0} is plume dispersion parameter (the standard deviation in the cross wind direction of the plume concentration distribution) for the evaluation time t and t_0 for each, and p is 0.2 for t= 3 min ~ 1 hour, and is 0.25 ~ 0.3 for t is 1 hour ~ 100 hours.



Atmospheric turbulence power spectrum

•Application of the diffusion equation to various conditions

The stack gas can be considered as a **point source**, and such as the diffusion from automobiles on a road is treated as a **line source**. The line source diffusion equation can be obtained by the line integration of the point source diffusion equation.

For the case of **dust** diffusion, the diffusion equation can be applied **slanting the center of the plume** considering the sedimentation of the dust particles. This method can be applied the the evaluation of the **call dust diffusion** in the coal banker of the coal combustion thermal power plant.

•Puff model

When the stack gas is released **instantaneously**, not like a plume which is continuously released, the gas distribution is presented as follows and it is called **puff model**,

$$C = \frac{Q}{(2\pi)^{3/2} U \sigma_x \sigma_y \sigma_z} \exp\left[-\frac{(x-Ut)^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2}\right]\left\{\exp\left[-\frac{(z-H_e)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H_e)^2}{2\sigma_z^2}\right]\right\}$$

c. Numerical Integration model

The rapid progress of the computer, makes the numerical integration model (**numerical model** in followings) easy to use for the atmospheric diffusion evaluations. The numerical model is based on the kinetic equations and diffusion equations, and the similarity is according to the accuracy of the **parametrization** of the model.

•Eular type K-theory diffusion model

The diffusion equation is presented as,

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial y} = \frac{\partial}{\partial x}\left(K_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial C}{\partial z}\right),$$

where, C denotes the concentration [m^3/m^3], u, v, w : wind speed [m/s] for x, y, z-direction, and the each Kx, Ky, Kz is the eddy diffusion coefficient [m^2/s] for x, y, z-direction. Using the **calculus finite difference**, the above **differential equation** is converted to **difference equation**, and can be solved numerically.

•Lagrange type particle diffusion model

This method emulates the air pollutants with a lot of particles. Each particle is moved considering the mean wind and turbulent characteristics.

NOTE: Eular type means the method considering the phenomenon with the fixed coordinates. Lagrange type means that with the target associated coordinates.