Chapter 10 Air Pollution Estimating Techniques

10.1 The Theory of Atmospheric Diffusion

As for smoke which is discharged into the atmosphere, advection by the wind and diffusion by the wind turbulence work to dilute it. The dilution by the advection of the wind is proportional to the wind velocity. Fig.10.1.1 illustrates the dilution by the wind. The ○ in the figure represents smoke as separate masses (called puffs). When we assume that the puff is discharged 1-second intervals, the distance between contiguous puffs is proportional to wind velocity. In other words, when the wind velocity is 1 m/s, the distance becomes 1 m and at a wind velocity of 2 m/s, it becomes 2 m. The distance between contiguous puffs shows the dilution effect. In another words, the concentration is inversely proportional to the velocity.

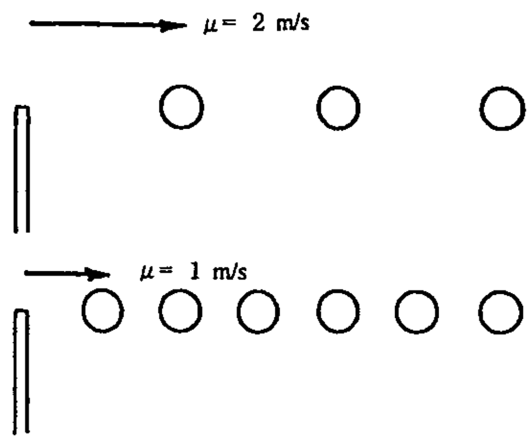

Fig.10.1.1 The dilution effect of wind velocity

Therefore, although this overlaps with some of Chapter 4, we consider in this chapter the wind and the structure of the surface layer of the atmosphere. The wind blows around, over or through trees, forests, mountains and clusters of high-rise buildings in cities. The irregularity of these ground-surface is called roughness. The roughness disturbs air flow and produces eddies and turbulence (Fig.10.1.2). In the turbulent air flow, wind velocity and direction changes time to time. The flow where the direction of the wind and its velocity change randomly is called the turbulent flow. The wind in the atmosphere is the most typical turbulent flow. The turbulence of the wind created by the roughness of the ground is the strongest near the ground surface and decreases as it rises in the sky. The atmospheric layer where the airflow is influenced by the ground surface is called the atmospheric boundary layer. The wind velocity and the turbulence changes with the altitude in the atmospheric boundary layer. In other words, the wind velocity is weak near the ground surface due to the drag force of the ground, but it increases at higher altitudes.

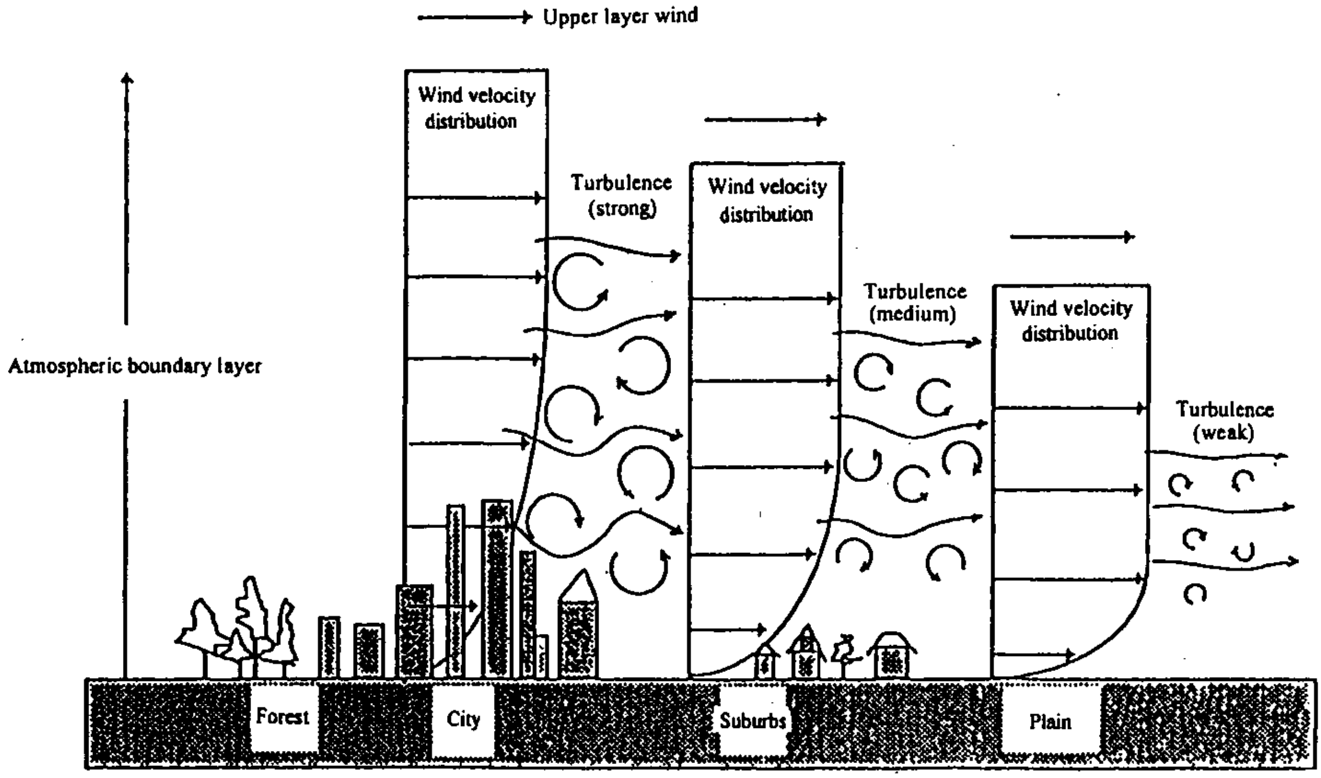

Fig.10.1.2 Generation of turbulence in the atmosphere by the ground surface incongruity and the atmospheric boundary layer

Differences in temperature exist at ground level such as the temperature of the surface of the water and the ground in addition to the roughness. Also, convection occurs because solar radiation can warm the ground surface during the day in fine weather and the temperature of the air near the ground level rises. This convection motion is one of the biggest causes of turbulence in the wind. The atmospheric boundary layer where the convection is active in the daytime is called the mixing layer. On the other hand, convection is weak when it is cloudy, but the atmospheric boundary layer where the effect on wind velocity is dominant is called a neutral boundary layer.

On a night of fine weather, heat escapes from the ground surface into the sky through infrared radiation. Thus, the temperature of the ground surface falls and the air near the ground is also chilled. The vertical temperature of the atmosphere falls rapidly near the ground level. This air layer is called the ground inversion layer. The turbulence of the wind decreases in the inversion layer. The concept of the atmospheric boundary layer with the mixing layer, the neutral boundary layer and the ground inversion layer is shown in Fig.10.1.3.

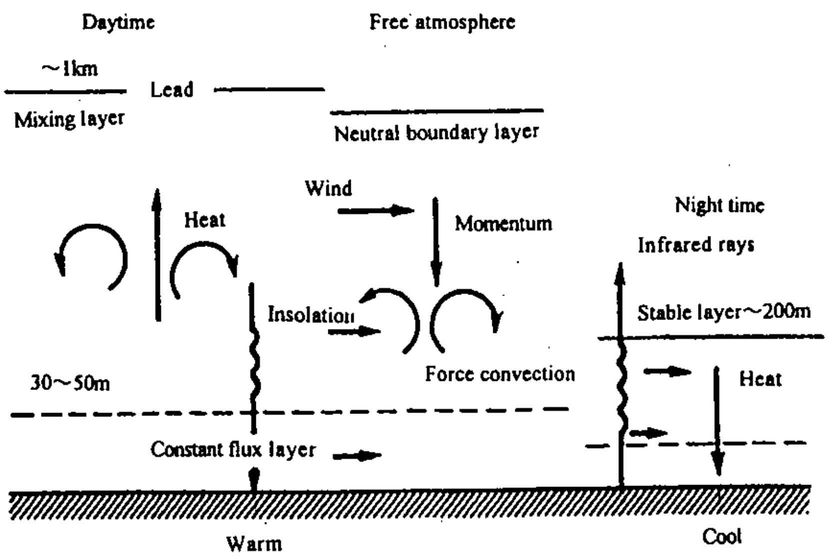

Fig.10.1.3 Origin and the classification of the atmospheric boundary layer

Generally, the temperature decreases up wards in the atmosphere. The temperature lapse rate is 0.98C for every 100 m when the atmosphere is of dry air and the movement of the air mass is supposed to be adiabatic. This is called a dry adiabatic lapse rate and is shown by the symbol γ_d. When the rate of temperature decrease is larger than γ_d, then the vertical motion of the air mass accelerated by the buoyancy effect, it is said that the atmosphere is in an unstable condition (Fig.10.1.4). On the other hand, when the lapse rate is smaller than γ_d, the vertical motion of the air mass is suppressed by the buoyancy force and turbulence become small. It is said that the atmosphere is in a stable condition. The layer of the atmosphere where the temperature increases up wards, is called temperature inversion layer. The inversion layer is a very strong stable condition and it emerges on a night of fine weather when the wind is weak. The relationship between the vertical temperature profile and the thermal stability of the atmosphere is shown in Fig.10.1.4.

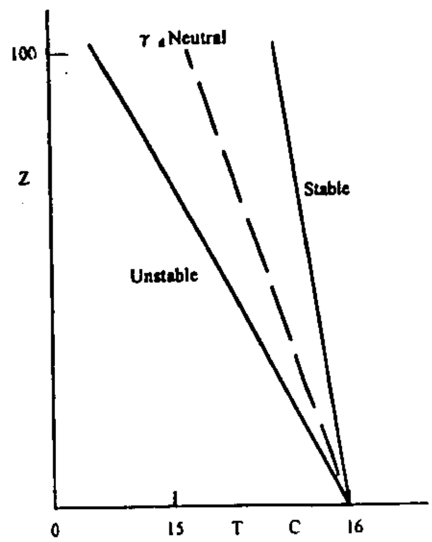

Fig.10.1.4 The atmosphere temperature inclination and atmospheric stability

Next, we will consider the relationship between turbulence and the diffusion by the wind. As for the wind, velocity and direction change every moment. The wind's vector deviates from the average to average. The deviation velocity from the average is called turbulent velocity. The turbulence component is deviled into the horizontal wind component and the vertical wind component. The root mean square of the turbulence component is called turbulence intensity. The relationship between the change of the wind and the diffusion is easily understand by considering movement of a particle in the turbulent flow (Fig. 10.1.5). The particles in the smoke, drift up and down, left and right. If the turbulence of the wind is strong, the diffusion of the smoke is also big.

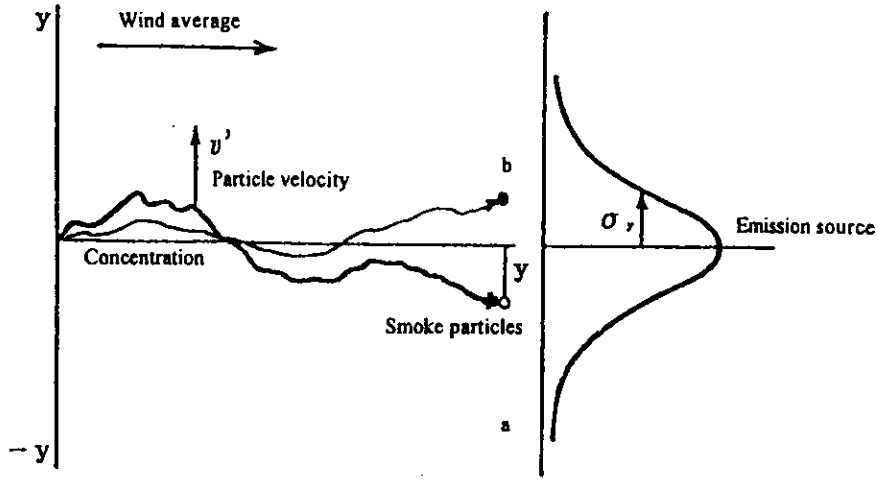

Fig. 10.1.5 The diffusion of particles and the concentration profile

The idea of diffusion easily understand by releasing and tracking many particles as can be seen in Fig. 10.1.5. The weight and size of the particulate in the smoke can be disregarded. When looking at the expanse of the particulate group on the downwind side, the number diminishes as most of the particles leave the flow as the average direction of the wind becomes prolonged. This shows the particulate concentration. The concentration profile of the smoke is the biggest in the center and this distribution profile is called a logarithnic profile or a Gaussian profile. The standard deviation of this distribution function is called the plume width of the smoke (Fig. 10.1.5). This is illustrated in Eq. (1) when showing a concentration profile mathematically.

$$C(y) = C_0 \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \quad \cdots\cdots (1)$$

Here, σ_y is the direction of the plume width. Also, C_0 shows the concentration at the plume axis. The turbulent flow in which the turbulence characteristic is independent to direction and place is called an isotropic turbulence. In the isotropic turbulence, plume width σ_y is given by Eq. (2) with σ_v the size of the turbulent flow.

$$\sigma_y = \{2\sigma_v^2 \int_0^T (T-\xi) R(\xi)\, d\xi\}^{\frac{1}{2}} \quad \cdots\cdots (2)$$

Here, T is the floating time of the smoke in the airflow and R (ξ), the statistical characteristics of the turbulent flow, called auto-correlation function. R (ξ) is 1 when ξ is 0, and, as ξ increases R (ξ) approaches 0. The plume width is changeable by stability of the atmosphere, but this is described in the following paragraph.

The diffusion coefficient is another way of describing diffusion. For example, it is possible to show the distribution of the concentration as in Fig. 10.1.6 with z at some point, flux $F(z)$ by the diffusion of the smoke in the direction as shown in Eq. (3).

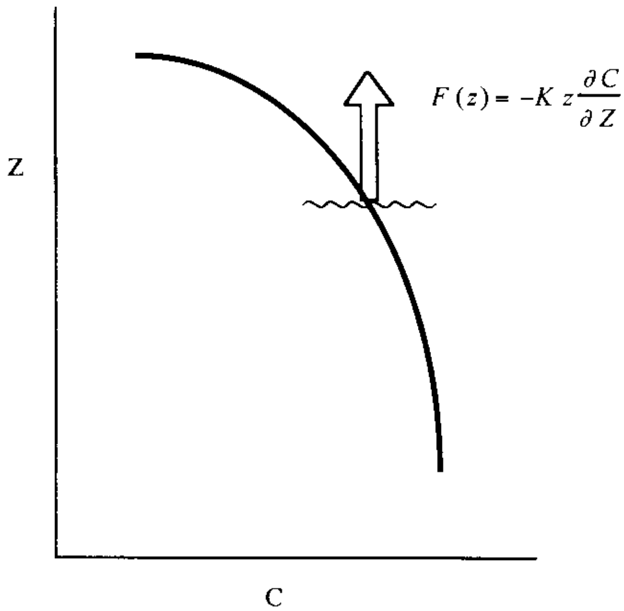

Fig. 10.1.6 The relationship between the flux material Fz and the concentration gradient

$$F(z) = -Kz\frac{\partial C}{\partial z} \qquad \cdots\cdots (3)$$

The diffusion coefficient Kz changes by the stability of the atmosphere.

The above is an analytical solution for diffusion and there is a theoretical method to treat diffusion by using the diffusion coefficient.