CHAPTER III

FUNDAMENTAL KNOWLEDGE

To visualize the causes of fugitive dust problem and the factors influenced on the transportation of such pollutant, this chapter provides the fundamental knowledge on the typical stone crushing process as well as the atmospheric dispersion principle of pollutant from a single point source. In the last section, this chapter also presents a brief introduction of basic principle of stochastic process simulation and Monte-Carlo technique, which is applied in present work.

3.1 Stone Crushing Process

In the beginning of stone crushing process, rock and crushed stone products generally are loosened by drilling and blasting, then are loaded by power shovel or front-end loader into large haul trucks that transport the material to the processing operations. Techniques used for extraction vary with the nature and location of the deposit. In general, the processing operations include crushing, screening, size classification, material handling, and storage operations. All of these processes can be significant sources of PM and PM-10 emissions if uncontrolled.

Quarried stone is normally delivered to the processing plant by truck and is dumped into a hoppered feeder, usually a vibrating grizzly type, or onto screens, as illustrated in Figure 3.1. The feeder or screens separate large boulders from finer rocks that do not require primary crushing, initial reduction. The crusher product, normally 7.5 to 30 centimeters (3 to 12 inches) in diameter, and the grizzly throughs (undersize material) are discharged onto a belt conveyor and usually are conveyed to a surge pile for temporary storage, or are sold as coarse aggregates.

The stone from the surge pile is conveyed to a vibrating inclined screen that called the scalping screen. This unit separates oversized rock from the smaller stone. The undersize material from the scalping screen is considered to be a product stream and transported to a storage pile and sold as base material. The stone that is too large to pass through the top deck of the scalping screen is processed in the secondary crusher. Cone crushers are commonly used for secondary crushing, which typically reduces material to about 2.5 to 10 centimeters. The material from the second level of the screen bypasses the secondary crusher because it is sufficiently small for the last crushing step. The output from the secondary crusher and the throughs from the secondary screen are transported by conveyor to the tertiary circuit, which includes a sizing screen and a tertiary crusher.

Tertiary crushing is usually performed using cone crushers or other types of impactor crushers. Oversize material from the top deck of the sizing screen is fed to the tertiary crusher. The tertiary crusher output, which is typically about 0.50 to 2.5 centimeters, is returned to the sizing screen. Various product streams with different size gradations are separated in the screening operation. The products are conveyed or trucked directly to finished product bins, open area stockpiles, or to other processing systems such as washing, air separator, and screens and classifiers.

Some stone crushing plants produce manufactured sand. This is a small-sized rock product with a maximum size of 0.50 centimeters. Crushed stone from the tertiary sizing screen is sized in a vibrating inclined screen (fines screen) with relatively small mesh sizes. Oversized material is processed in a cone crusher or a hammermill (fines crusher) adjusted to produce small diameter material. The output is then returned to the fine screen for resizing. In certain cases, stone washing is required to meet particular end product specifications or demands as with concrete aggregate processing. Crushed and broken stone normally is not milled but is screened and shipped to the consumer after secondary or tertiary crushing.

Apparently, from overall stone crushing process described above, emissions of PM and PM_{10} occur from a number of operations in stone quarrying and processing. A substantial portion of these emissions consists of heavy particles that may settle out within the plant. As in other operations, crushed stone emission sources may be categorized as either process sources or fugitive dust sources. Process sources include those for which emissions are amenable to capture and subsequent control. Fugitive dust sources generally involve the reentrainment of settled dust by wind or machine movement. Emissions from process sources should be considered fugitive unless the sources are vented to a baghouse or area contained in an enclosure with a forced-air vent or stack. Factors affecting emission from either source category include the stone size distribution and surface moisture content of the stone processed; the process throughput rate; the type of equipment and operating practices used and topographical and climatic factors. However, those variety of material, equipment, and operating factors influenced emissions from stone crushing can be generally classified as (i) stone type, (ii) feed size and distribution, (iii) moisture content, (iv) throughput rate, (v) crusher type, (vi) size reduction ratio, and (vii) fine content.

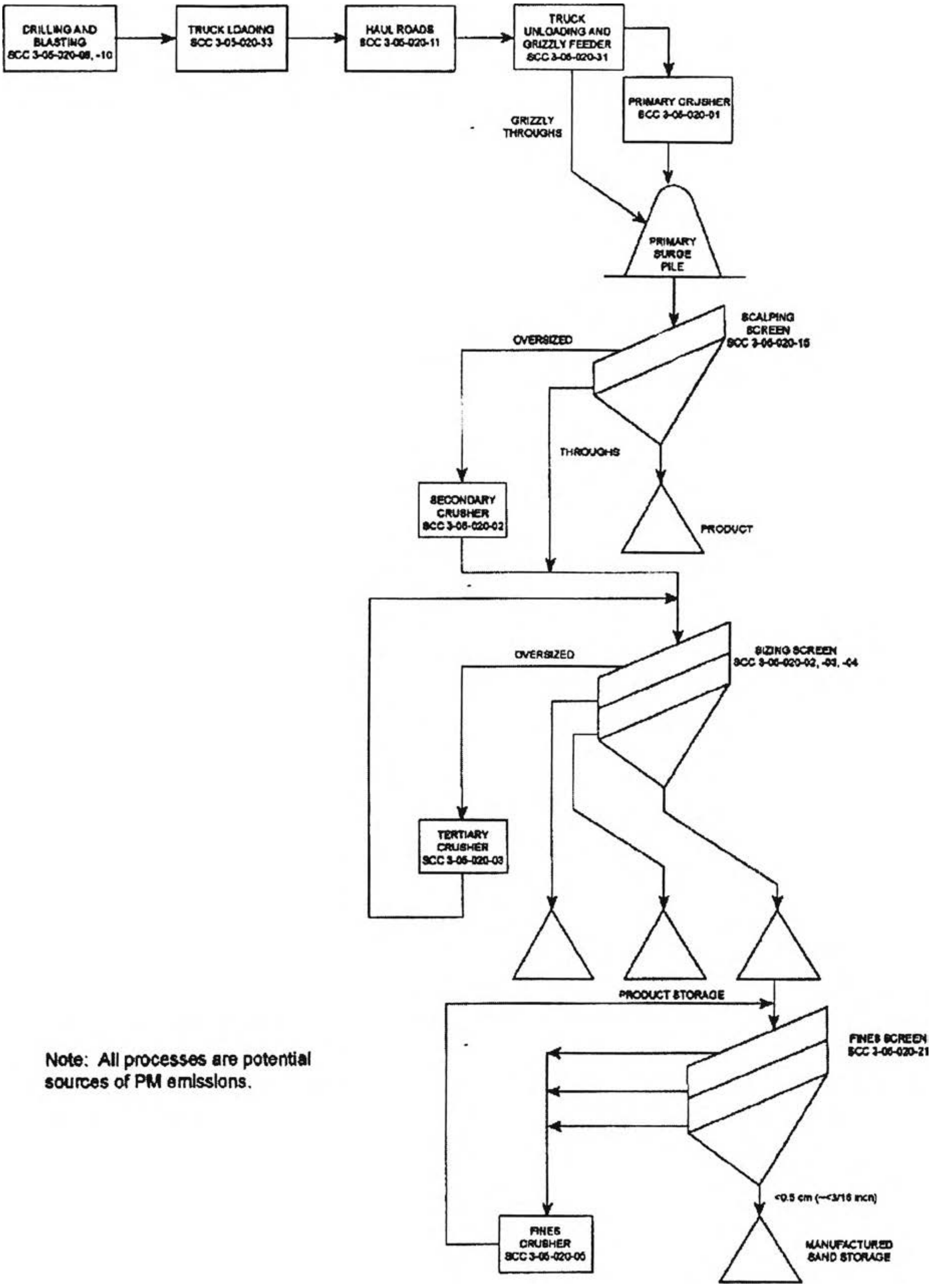

Figure 3.1 Typical stone crushing process.

3.2 Air Pollution Dispersion

The dispersion of air pollutant in the atmosphere is influenced by the degree of stability of the atmosphere or characteristics of the atmospheric turbulence, horizontal wind, features of terrain and so on. In this topic, some basic principles of meteorology dealing with air pollution dispersion and the mixing process of air pollution are defined.

3.2.1 Atmospheric Turbulence

Turbulence consists of circular whirls or eddies of all possible orientations, horizontal eddies, vertical eddies and all orientations in between. These turbulent eddies serve to disperse pollutants by mixing with air surrounding it and then diluting the pollutant concentrations. The causes of these eddies or whirls are primarily due to mechanical or buoyant generation of turbulence. In general, atmospheric turbulence could be categorized into two types as followings;

1) Mechanical eddies result from the shearing forces produce when the wind blows over the surface of the earth. At ground level the wind speed is zero, and it reaches a maximum usually at many thousands of meters above the surface. Mechanical turbulence increases with increasing wind speed and is greater over rough surface than over smooth surface.

2) Buoyant eddies are formed in the atmosphere by convection and by geographic and man-made structures. Convection occurs when air is heated from below by the warm surface of the earth and by the buildings and pavement covering it. Whenever the temperature decreases rapidly with height, convection is most pronounced and may persist up to many hundreds of meters above the surface on clear days.

3.2.1.1 Lapse Rate

Lapse rate is the rate at which the ambient temperature is found to decrease with altitude. The value of the lapse rate in the lower portion of the troposphere has a profound influence on the vertical motion of air. Suppose that a parcel of air commences to rise in a dry atmospheric without mixing or heat exchange between the air parcel and its environment, the air parcel will expand and cool adiabatically. The cooling is said to be at the dry adiabatic lapse rate. Thus, the dry adiabatic lapse rate can be defined as the negative of the temperature gradient that is established as dry air expands adiabatically while ascending. And the term of temperature gradient has the opposite algebraic sign from the lapse rate. Both temperature gradient and lapse rate are used when discussing the temperature structure of the atmosphere.

3.2.1.2 Atmospheric Stability Classification

In 1961, Pasquill introduced a method of estimating the atmospheric stability, it is assumed that stability in the layers near the ground is dependent on net radiation as an indication of buoyant eddies and on wind speed as an indication of mechanical eddies.

The major features of this method are given in Table 3.1. The mechanical turbulence is considered by the inclusion of the surface (approximately 10-meter above ground) wind speed. The positive generation of buoyant turbulence is considered through the insolation (incoming solar radiation) or solar altitude, which is a function of latitude, day of the year, and time of day. The negative generation of buoyant turbulence is considered through the nighttime cloud cover. The less the cloud cover the greater the amount of heat that escapes from the surface through infrared radiation. High wind speeds or overcast cloudiness will produce neutral conditions, D class stability. Unstable conditions are strongly unstable, A; moderately unstable, B; and slightly unstable, C. Stable conditions are slightly stable, E; and moderately stable, F. The hyphens at low wind speeds at night can be considered strongly stable, and sometimes are referred to as "G"(Turner, 1994).

Table 3.1 Pasquill-Gifford Stability Classification.

Surface wind speed , m/s (at 10m)	Day-Time Insolation			Night-Time Cloudiness	
	Strong	Moderate	Slight	Thinly overcast or $\geq$ 4/8 cloud	Clear or $\leq$ 3/8 cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

Notes: 1) The degree of cloudiness is defined as that fraction of sky above the local apparent horizon that is covered by clouds.

2) Night refers to the period from 1 hour before sunset to 1 hour before sunrise.

3) Regardless of wind speed, the neutral category D should be assumed for overcast conditions during day and night and for any sky conditions during the hour preceding or following night.

4) Strong insolation corresponds to a solar elevation angle of 60° or more above the horizon. Slight insolation corresponds to a solar elevation angle of 15° to 35°.

3.2.1.3 Inversion

An inversion is a vertical temperature structure that is inverted from the usual decrease of temperature with height that may be based at the surface or in the upper air. Inversion layers play an important role in influencing the dispersion of air pollutants by restricting vertical mixing. Generally, inversions are classified according to the method of formation and according to the height of the base, the thickness, and intensity. For example, a surface inversion usually occurs on clear nights with low wind speed. In this situation the ground cools rapidly due to the prevalence of long wave radiation to the outer atmosphere. While the surface of earth is cooling, the surface air becomes cooler than the air above it, and vertical air flow is halted. In the morning the sun warms the surface of the earth, and the breakup of the inversion is rapid. Smoke plume from stacks are quite often trapped in the stable radiation inversion layer at night and then brought to the ground in a fumigation during morning hours which results high ground-level concentration.

3.2.1.4 Plume Types

A plume from an elevated source such as a tall exhaust stack mixes vertically and horizontally with ambient air as it drifts downwind. Vertical mixing is determined largely by the degree of instability of the lower troposphere; this it depends upon the temperature profile. Horizontal mixing can also be influenced indirectly by the lapse rate, for a movement somewhere. On the other hand, even if vertical circulation is suppressed by a stable lapse rate, horizontal motion is possible. Therefore the spread of a plume in the horizontal direction may be unequal to the vertical spread at a given distance downwind from the stack.

Figure 3.2 shows the vertical expansion of continuous plumes related to vertical temperature structure. The dashed lines correspond to the dry adiabatic lapse rate for reference. Part (a), (b), and (c) of Figure 3.1 illustrate three examples of a plume being dispersed when it is affected by a uniform lapse rate. In part (a), large-scale turbulent eddies cause sizable parcels of air, together with portions of the plume, to deviate from a straight downwind direction. This condition is known as looping and may occur when the atmosphere is highly unstable. If a plume temporarily loops downwind, it can cause a momentary high concentration of pollutant at ground level near the stack. In part (b), the lapse rate is essentially neutral and the shape of the plume commonly is vertically symmetrical about what is called the plume line. Its conical shape suggests the name coning. The most confined plume is found in a stable lapse rate as shown in (c). The lapse rate suppresses vertical mixing, but not horizontal mixing entirely. The plume spreads only parallel to the ground and appears to take on a fan shape as seen from below. On occasion, plumes in a stable layer may be followed for 10 or 20 km downwind from the source. They are often observed early in the morning when the effluent is still trapped in a ground-based radiational inversion.

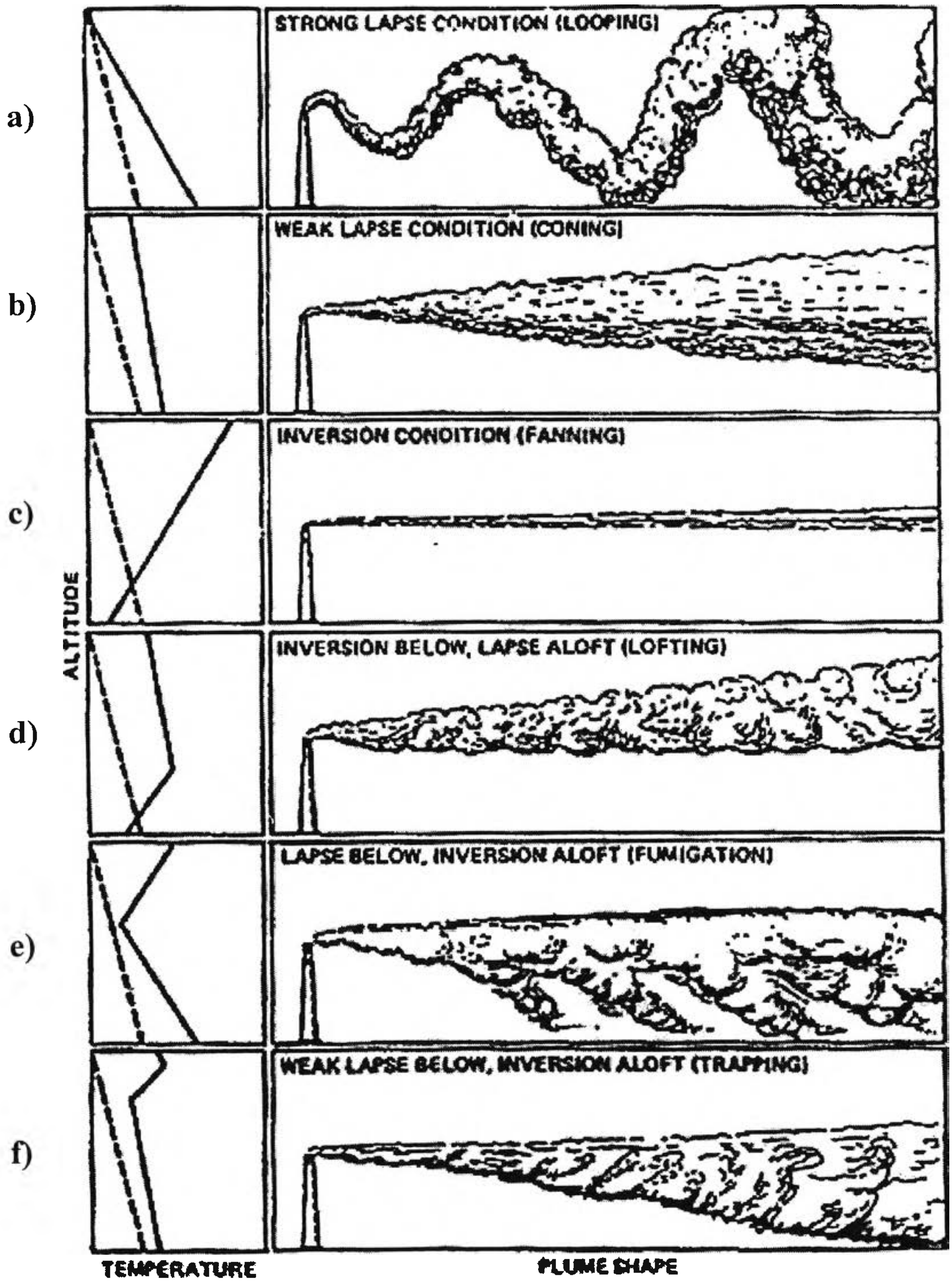

Figure 3.2 Plume behavior influenced by the lapse rate and inversion layer above and below the release height.

Two meteorological conditions of special interest are found when the lapse rate changes from stable to unstable at a height which is approximately where the plume is released. One case is illustrated in part (d) where the lapse rate in the upper portion of the plume is unstable, and in the lower, it is stable. Mixing vigorous in the upward direction, a circumstance known as lofting. This is advantageous, for pollutants can be well mixed into the upper air while barely affecting people on the ground. The second case, illustrated in part (e), poses a potentially serious air pollution situation. Here the plume is released just under an elevated inversion layer; perhaps a ground-based inversion has been eroded from beneath, as occurs in the morning as the ground warms. When the low-level toward the ground, an effect called fumigation. Same as the last case, as shown in part (f), the release height is below the inversion layer and then the plume is trapped and cause the ground-level concentrations of pollutants increase because upward dispersal is discouraged by the inversion layer.

3.2.2 Effect of Wind

Wind is a velocity and a vector quantity having a direction and speed, which are strongly affected by the surface conditions, the nature of the surface, predominant topological features such as hills and valleys, and the presence of lakes, rivers, and buildings. Besides, wind patterns also vary in time, for example, from day to night, etc. Although the wind vector can occur in three dimensions, it is common only to consider the horizontal components of the wind. By convention the wind direction is the direction from which the wind comes. For the airport observations the wind is reported with a resolution of 10 degree. The North is 0 degrees or 360 degrees, and the East is 90 degrees.

The effect of wind speed on atmospheric dispersion is to determine how much the pollutant is diluted and blown away, while the effect of wind direction is to determine in which direction this dilution and spreading takes place. Since wind direction is the direction from which the wind blows, a west wind would cause pollution to move toward the east from the source.

3.2.3 Effect of Topography

The effect of topography could be categorized into two aspects as itself terrain effect and effect of elements on the surface, which usually depend on the type of land-use. Both effects have a great influence on the local weather and wind patterns as well as the other factors affecting atmospheric dispersion.

3.2.3.1 Terrain Effect

Local airflow patterns are greatly influenced by juxtaposed geographic configurations. For example, mountains and valleys, a mountain pass, or a land-water-air interface. There is an infinite variety of flow patterns that can result from topographical or man made obstacles. For instance, vortices rotating in the vertical plane are formed when air flows over an obstacle and the separation of the flow may occur. Smoke plumes can be caught in these vortices and forced down to the ground. In case the separation of flow occurs around a building or behind a chimney, atmospheric dispersion effects can result in the cavities that form behind buildings or chimneys, where low-pressure areas are formed and the smoke plume may be drawn downwards in what is called “stack downwash”.

3.2.3.1 Effect of Surface Roughness

The objects on the surface (roughness elements) over which the wind is flowing will have a frictional effect upon the wind speed nearest the surface. This effect is depicted in Figure 3.3 for three different surfaces. The numbers given at various heights are the wind speed at that height relative to the gradient wind, in percent. The gradient wind occurs at the height above the surface where the effects of the surface are no longer felt. It can be considered as the free-stream flow and is in response to the pressure and temperature gradients. Both the height and the spacing of the roughness elements on the surface will influence the frictional effect on the wind. A single parameter, the surface roughness length, z_0, is used to signify this effect. Typical values of z_0 are given in Table 3.2 (Schnelle, K. B., 2000).

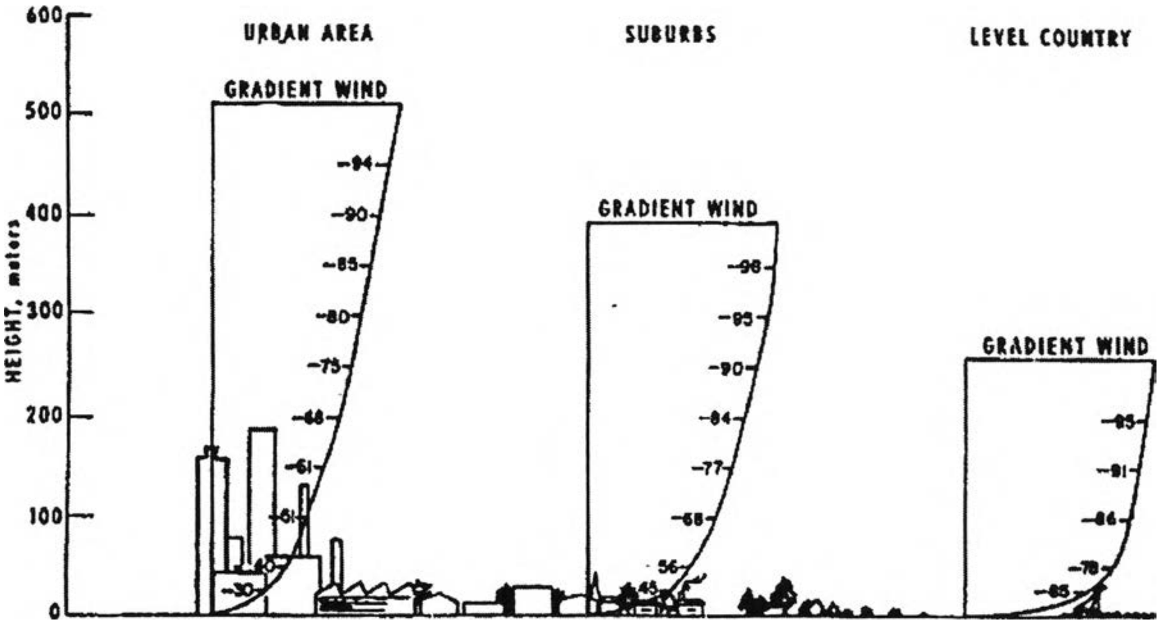

Figure 3.3 Effect of terrain roughness on the wind speed profile over different size roughness elements.

Table 3.2 Value of Surface Roughness Length (z_o), for typical surface.

Typical surface	Surface roughness length (z_o), cm
Smooth mud flats	0.001
Smooth snow	0.005
Smooth sea	0.02
Level desert	0.03
Snow surface, lawn grass to 1.0 cm high	0.1
Lawn, grass to 5 cm	1 to 2
Lawn, grass to 60 cm	4 to 9
Fully grown root crops	14
Pasture land	20
Suburban housing	60
Forest, cities	100

Since it is impossible to make measurements of resulting air quality for a facility that has not yet been constructed, air quality modeling is about the only way to estimate such future impact. The preceding section describes the available atmospheric dispersion models, particularly, the models that rely on the Gaussian dispersion approach.

3.3 Atmospheric Dispersion Model

An atmospheric dispersion model is a mathematical expression relating the emission of material into the atmosphere to the downwind ambient concentration of the material. The heart of the matter is to estimate the concentration of a pollutant at a particular receptor point by calculating from some basic information about the source of the pollutant and the meteorological data.

The U.S. Environmental Protection Agency (U.S. EPA) has developed a series of atmospheric dispersion program available through the EPA's Office of Air Quality Planning and Standards (QAQPS) and divided the air quality models into four generic classes; (i) Gaussian models, (ii) numerical models, (iii) statistical or empirical models, and (iv) physical models.

Gaussian models, which are the most widely used, are recommended for estimating the impact of nonreactive pollutants. Numerical models (i.e., grid models or box models) are suggested for urban application involving reactive pollutants (e.g., photochemical smog). Other models can be used for particular applications. Moreover, the models are categorized by two levels of sophistication:

1) Screening models, which are relatively simple estimation techniques that provide conservative estimates of air quality impacts. In several cases, they can eliminate from further consideration those sources that clearly do not contribute to ambient concentration.

2) Refined models, which provide a more detailed treatment of physical and chemical processes, require more detailed and precise input data, have higher computational costs, and provide (at least theoretically) a more accurate estimate of the source impact and the effectiveness of different control strategies.

Besides, the U.S. EPA also divides the air quality models recommended in its guideline into "preferred" and "alternative" models. Preferred models are those that EPA either found to perform better than others in a given category, or chose on the basis of other factors such as fast use, public familiarity, cost or resource requirements, and availability. These preferred models can be used for regulation applications without a formal demonstration of applicability. Alternative models can be used when (i) a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (ii) a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the application than a comparable preferred model; (iii) there is no preferred model for the specific application but a refined model is needed to satisfy regulatory requirements.

Table 3.3 concludes the features of U.S. EPA's preferred models. Obviously, the ISC3 model offers modelers several options in estimating of pollutant from various sources. Furthermore, it also includes an algorithm of dry and wet deposition for particulate simulation, and since the present study's objective focus on the investigation of PM_{10} spreading over the non-simple terrain with the dry deposition consideration, thus it can be reasonably said that the ISC3 model is the most proper model to simulate the concentration of PM_{10} in this work.

Table 3.3 Features of U.S. EPA's preferred air quality models

Model	Features	Recommendations for Regulatory Use
Buoyant Line and Point Source Dispersion Model (BLP)	BLP is a Gaussian plume dispersion model designed to handle unique modeling problems associated with aluminum reduction plants and other industrial sources where plume rise and downwash effects from stationary line sources are important.	BLP model is appropriate for the following applications: • Aluminum reduction plants that contain buoyant, elevated line sources • Rural area • Transport distance less than 50 km • Simple terrain • One-hour to one-year averaging times
CALINE 3	CALINE 3 can be used to estimate the concentrations of nonreactive pollutants from highway traffic. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of "at-grade", "fill", "bridge", and "cut section" highways located in relatively uncomplicated terrain.	CALINE 3 is appropriate for the following applications: • Highway (line) source • Urban or rural areas • Simple terrain • Transport distance less than 50 km • One-hour to 24-hour averaging time

Table 3.3 Features of U.S. EPA's preferred air quality models (cont.)

CDM 2.0	CDM is a climatological steady-state Gaussian plume model for determining long-term (seasonal or annual) arithmetic average pollutant concentrations at any ground-level receptor in an urban area.	CDM is appropriate for the following applications: • Point and area sources • Urban areas • Flat terrain • Transport distance less than 50 km • Long-term averages over one month to on year or longer
Gaussian Plume Multiple Source Air Quality Algorithm (RAM)	RAM is a steady-state Gaussian plume model for estimating concentration of relatively stable pollutants, for averaging times from an hour to a day, from point and area sources in a rural or urban setting and level terrain is assumed.	RAM is appropriate for the following applications: • Point and area sources • Urban areas • Flat terrain • Transport distance less than 50 km • One-hour to one-year averaging times

Table 3.3 Features of U.S. EPA's preferred air quality models (cont.)

Industrial Source Complex 3 Model (ISC3)	ISC model is a steady-state Gaussian plume model that can be used to assess pollutant concentration from a wide variety of sources associated with an industrial source complex. This model can account for the settling and dry deposition of particulates; downwash; area/ point/ line and volume sources; plume rise as a function of downwind distance; seperation of point souces; and limited terrain adjustment. It operates in both long-term and short-term modes.	ISC is appropriate for the following applications: • Industrial source complex • Rural or urban areas • Flat or rolling terrain • Transport distance less than 50 km • One-hour to annual averaging times
Multiple point Gaussian Dispersion Algorithm with Terrain Adjustment (MPTER)	MPTER is a multiple point source algorithm. This algorithm is useful for estimating air quality concentration of relatively non-reactive pollutants. Hourly estimates are made using the Gaussian steady-state model.	MPTER is appropriate for the following applications: • Point sources • Rural or urban areas • Flat or rolling terrain (no terrain above stack height) • Transport distance less than 50 km • One-hour to one-year averaging times

Table 3.3 Features of U.S. EPA's preferred air quality models (cont.)

Single Source (CRSTER) Model	CRSTER is a steady-state Gaussian dispersion model designed to calculate concentrations from point sources at a single location in either a rural or urban setting. Highest and highest second-highest concentration are calculated at each receptor for 1-hour, 3-hour, 24-hour, and annual averaging times.	CRSTER is appropriate for the following applications: • Single point sources • Rural or urban areas • Flat or rolling terrain (no terrain above stack height) • Transport distance less than 50 km
Urban Airshed Model (UAM)	UAM is an urban-scale, three-dimensional, grid-type, and numerical simulation model. The model incorporates a condensed photochemical kinetics mechanism for urban atmospheres. The UAM isdesigned for computing ozone (O_3) concentrations under short-term, episodic conditions lasting one or two days resulting from emissions of oxides of nitrogen (Nox) and volatile organic compounds (VOC). The model treats urban VOC emissions as their carbon-bond surrogates.	UAM is appropriate for the following applications: • Single urban areas having significant ozone attainment problems in the absence of interurban emission transport • One-hour averaging times

Table 3.3 Features of U.S. EPA's preferred air quality models (cont.)

Offshore and Coastal Disperion Model (OCD)	OCD is a straight-line Gaussian model developed to determine the impact of offshore emissions from point sources on the air quality of coastal regions. OCD incorporates overwater plume transport and dispersion as well as changes that occur as the plume crosses the shoreline. Hourly meteorological data are needed from both offshore and onshore locations. These include water surface temperature, overwater air temperature, and relative humidity.	OCD is recommended for emissions located on the outer continental shelf and applicable for overwater sources where onshore receptors are below the lowest source height. Where onshore receptors are above the lowest source height, offshore plume transport and dispersion may be modeled on a case-by-case basis in consultation with the U.S. EPA regional office.

3.4 Gaussian Dispersion Model

The Gaussian plume model is the most common air pollution model. It is based on a simple formula that describes the three-dimensional concentration field generated by a point source under stationary meteorological and emission conditions. The assumptions of Gaussian modeling are briefly concluded as the follows;

1) The emissions of pollutant in mass per time are taking place continuously and the rates of these emissions are not variable over time.
2) During the transport of pollutants from source to receptor, the mass that is emitted from the source is assumed to remain in the atmosphere. None of the material is removed through chemical reaction nor is lost at the ground surface through reaction, gravitational settling, or turbulent impaction. It is assumed that any of the released pollutant that is dispersed close to the ground surface by other subsequent turbulent eddies.
3) The meteorological conditions are assumed to persist unchanged with time, at least over the time period of transport (travel) time from source to receptor.
4) It is assumed that the time averaged (over about one hour) concentration profiles at any distance in the crosswind direction, horizontal (perpendicular to the path of transport) are well represented by a Gaussian, or normal, distribution and similarly, concentration profiles in the vertical direction (also perpendicular to the path of transport) are also well represented by a Gaussian distribution.

The Gaussian plume model is visualized in Figure 3.4, where the plume is advected toward the positive x-axis. In a general reference system, the Gaussian plume formula is expressed by

$$C(s,r) = \frac{Q}{2\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{\Delta_{cw}}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{z_s + \Delta h - z_r}{\sigma_z}\right)^2\right] \quad (3.1)$$

Where C (s,r) is the concentration at receptor [r = (x_r, y_r, z_r)] due to the emissions at source [s = (x_s, y_s, z_s)]; Q is the emission rate; σ_y, σ_z are the horizontal and vertical standard deviations of plume concentration spatial, respectively; Δ_{cw} is the crosswind distance between the receptor and source (i.e., between the receptor and the plume centerline); $\bar{u}$ is the average wind horizontal wind speed and Δh is the emission plume rise, which is a function of emission parameters, meteorology and downwind distance. By replacing the term $(z_s + \Delta h)$ with H, which is the effective emission height and $y_r = \Delta_{cw}$. Equation 3.1 is generally written in the form

$$C(x,y,z;H) = \frac{Q}{2\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y_r}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{H - z_r}{\sigma_z}\right)^2\right] \quad (3.2)$$

Equation (3.2), which is the basic Gaussian plume equation can be derived in several ways from different assumptions and can be justified by semiempirical considerations, as Figure 3.4 illustrates, where both instantaneous and the one-hour average concentration distributions are exemplified. Even though instantaneous plume concentrations are quite irregular, a sufficiently long averaging time (e.g. one hour) generates, in many bases, bell-shaped concentrations that can be well approximated by the Gaussian distribution in both the horizontal and vertical.

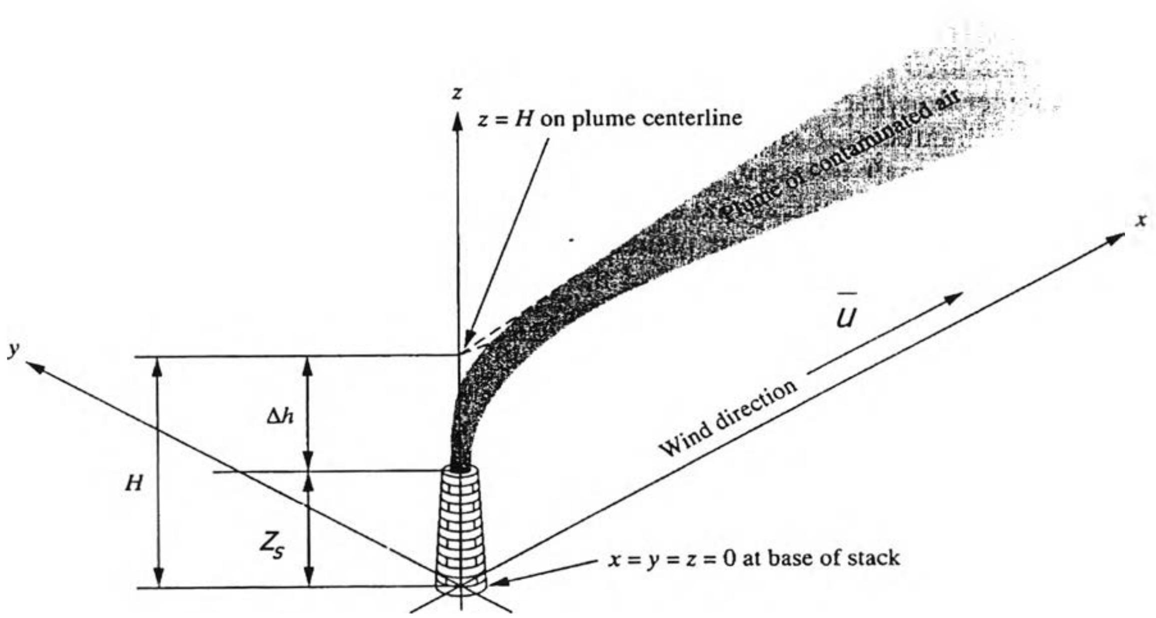

Figure 3.4 The Gaussian plume in a wind-oriented coordinate system.

To estimate σ_y or σ_z , the atmospheric stability class must first be determined, most of time, based on the typing techniques of Pasquill-Gifford or Turner. Then a series of curved or formulas are referenced to find values for σ_y and σ_z as a function of stability class, downwind distance, and averaging time. Figure 3.6 presents the Pasquill-Gifford dispersion parameters in the form of graph.

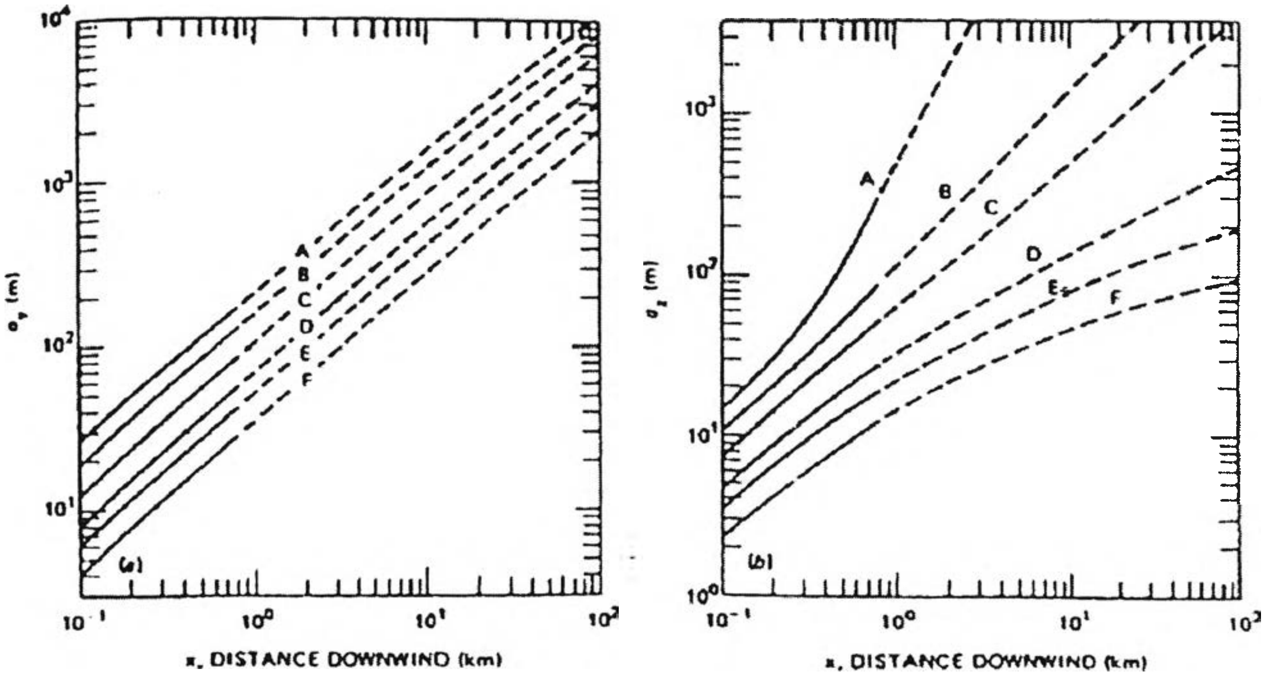

Figure 3.5 Pasquill-Gifford dispersion parameters as a function of stability and downwind distance

3.4.1 Industrial Source Complex (ISC) Model

The Industrial Source Complex (ISC) model is a stead-state Gaussian plume model most frequently used to assess pollutant concentrations from a wide variety of sources developed by U.S. EPA. The ISC model has two forms differentiated by the averaging time to be used, ISC short-term and ISC long-term models.

The ISC short-term (ISCST) model considers time periods of 1,2,3,4,6,8,12 and 24 hour and requires hourly meteorological data. Hourly concentrations are calculated in the basic computation for each source at each receptor and summed to obtain the total concentration produced at each receptor by the combined source emissions. The hourly averages are obtained by summing the hourly concentration over the period desired and dividing by the number of hourly periods used. Also, the ISCST model can be used to calculate annual concentration if used with a year of sequential hourly met data.

The ISC long-term (ISCLT) model uses sector averaging. It uses statistical wind summaries from the Stability Array (STAR) data meteorological information and then calculates seasonal or annual ground-level concentrations.

3.4.2 Industrial Source Complex Short-Term 3 (ISCST3) Model

The ISCST3 model, the latest version of ISCST model, provides options to model emissions from a wide range of sources that might be present at a typical industrial source complex. The basis of the model is the straight-line, steady-state Gaussian plume equation, which is used with some modifications to model simple point source emission from stack, emissions from stacks that experience the effects of aerodynamic downwash due to nearby buildings, isolated vents, multiple vents, storage piles, conveyor belts, and the like. Emission sources are categorized into four basic types of sources, i.e., point source, volume source, area source, and open pit source.

The ISCST3 model accepts hourly meteorological data records to define the condition for plume rise, transport, diffusion, and deposition. The model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages. For deposition values, either the dry deposition flux, the wet deposition flux, or the total deposition flux can be estimated. The total deposition flux is simply the sum of the dry and wet deposition fluxes at a particular receptor location. The user also has the option of selecting averages for the entire period of input meteorology.

3.4.3 Algorithm of the ISCST3 Model

This section describes a steady-state Gaussian plume equation used to model emission from point sources, such as stacks and isolated vents, including the plume rise formula, and the formula used for determining dry deposition concentration used in ISCST3 model.

3.4.3.1 Gaussian plume equation

For a steady-state Gaussian plume, the hourly concentration at downwind distance x and crosswind distance y is given by

$$C = \frac{QKVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2 \right] \tag{3.3}$$

where :

Q = pollutant emission rate (mass per unit time)

K = a scaling coefficient to convert calculated concentrations to desired units

V = a vertical term

D = a decay term

σ_y , σ_z = standard deviation of lateral and vertical concentration distribution (m)

u_s = mean wind speed at release height (m/s)

The vertical term (V), accounts for the vertical distribution of the Gaussian plume. It includes the effects of source elevation, receptor elevation, plume rise, limited mixing in the vertical, and the gravitational settling and dry deposition of particulates. In general, the effects on ambient concentrations of gravitational settling and dry deposition can be neglected for gaseous pollutants and small particulate (less than 0.1 microns in diameter). The vertical term without deposition effects is given by

$$V = \exp\left[-\frac{1}{2}\left(\frac{z_r - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z_r - H}{\sigma_z}\right)^2\right] + \sum_{i=1}^{\infty}\left\{\exp\left[-\frac{1}{2}\left(\frac{H_1}{\sigma_z}\right)^2\right]\right.$$
$$\left. + \exp\left[-\frac{1}{2}\left(\frac{H_2}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{H_3}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{H_4}{\sigma_z}\right)^2\right]\right\} \tag{3.4}$$

where :

$$H = h_s + \Delta h$$

$$H_2 = z_r + (2i\, z_i - H)$$

$$H_2 = z_r + (2i\, z_i - H)$$

$$H_3 = z_r - (2i\, z_i + H)$$

$$H_4 = z_r - (2i\, z_i + H)$$

H = effective stack height (m)

z_r = receptor height above the ground (flagpole) (m)

z_i = mixing height (m)

For the detailed informations of vertical term with dry deposition and other algorithms included in vertical term are available in user's guide for the ISC3 dispersion models (U.S. EPA, 1995).

The decay term (D) in Equation (3.4) is a simple method of accounting for pollutant removal by physical or chemical processes. It I of the form:

$$D = \exp\left(-\psi \frac{x}{u_s}\right) \qquad \text{for } \psi > 0$$

or

$$= 1 \qquad \text{for } \psi = 0 \qquad (3.5)$$

$$\psi = \frac{0.693}{T_{1/2}} \qquad (3.6)$$

where :

ψ = the decay coefficient (s-1) (a value of zero means decay is not considered)

x = downwind distance (m)

$T_{1/2}$ = pollutant half life (second)

3.4.3.2 Plume Rise Formula

The ISCST3 model uses Briggs plume rise equation to estimate the height of plume rise from a single point source. Equation (3.7) is the basic Briggs plume equation for estimating buoyant plumes for all atmospheric conditions.

$$\Delta h = \frac{1.6}{u}\left[g\, V_s\, P\left(\frac{d^2}{4}\right)\left(\frac{T_s - T_a}{T_s}\right)\right] x^{2/3} \tag{3.7}$$

where :

x = downwind distance from the source (m)

u = wind speed at stack top (m/s)

d = top inside stack diameter (m)

V_s = stack gas exit velocity (m/s)

g = acceleration of gravity, 9.8 m/s

P = atmospheric pressure (millibar)

T_s = stack gas temperature (K)

T_a = ambient air temperature (K)

3.4.3.3 Dry Deposition Algorithm

The deposition flux, F_d, is calculated as the product of the concentration, C_d , and a deposition velocity, V_d, computed at a reference height z_d :

$$F_d = C_d \times V_d \tag{3.8}$$

The concentration value, C_d, is calculated according to Equation (3.3) with deposition effects accounted for in the vertical term as described in section 3.4.3.1. The deposition velocity is written as the inverse of a sum of resistances to pollutant transfer through various layers, plus gravitational settling terms (Slinn, 1980; Pleim et al., 1984)

$$V_d = \frac{1}{r_a + r_d + r_a r_d V_g} + V_g \tag{3.9}$$

where :

V_d = the deposition velocity (cm/s)

V_g = the gravitational settling velocity (cm/s)

r_a = the aerodynamic resistance (s/cm)

r_d = the deposition layer resistance (s/cm)

In addition to the mass mean diameters (microns), particle densities (g/cm^3), and the mass fractions for each particle size category being modeled, The dry deposition algorithm also requires surface roughness length (cm), friction velocity (m/s), and Monin-Obukhov length (m), which are described in detail for model input in Chapter 4.

3.5 Process Simulation

Simulation is the process of replicating the real world based on a set of assumptions and conceived models of reality. It may be performed theoretically or experimentally. In practice, theoretical simulation is usually performed numerically; this has become a much more practical tool since the advent of computers. As with experimental methods, numerical simulation may be used to obtain (simulated) data, either in lieu of or in addition to actual real world data. In effect, theoretical simulation is a method of “numerical or computer experimentation”.

For engineering purposes, simulation may be applied to predict or study the performance and/or response off a system. With a prescribed set of values for the system parameters (or design variables), the simulation process yields a specific measure of performance or response. Through repeated simulations, the sensitivity of the system performance to variation in the system parameters may be examined or assessed. By this procedure, simulation may be used to appraise alternative designs or determine optimal designs.

3.6 Deterministic and Stochastic Process

Mathematical models can usually be derived from the applications of physiochemical principles. Such models are sometimes called “transport phenomena models”. Usually, the values of the model coefficients need to be determined experimentally. For complicated and little understood phenomena, process engineers can always resort to empirical models, which are very specific in nature and have only a limited range of transferability.

The term deterministic model is applied to a model in which there is no uncertainty in the values of the variables and parameters. However, because of measurement and instrumental errors as well as the effect of various uncontrollable and unknown factors, many real processes should be considered as stochastic, instead of deterministic, in nature.

A stochastic model is one in which the variables and parameters used to describe the input-output relationship are stochastic, that is, not known precisely but governed by certain probabilistic laws in stead. Thus, knowledge of the state of the variables and parameters at some moment in time will not uniquely determine a subsequent state (Tanthapanichakoon, 1978).

3.7 Stochastic Process Simulation (Monte-Carlo Simulation)

As the complexity of an engineering system increase, the required analytical model may become extremely difficult to formulate mathematically unless gross idealization and simplifications are invoked; moreover, in some cases even if a formulation is possible, the required solution may be analytically intractable. In these instances, a probabilistic solution may be obtained through Monte-Carlo simulations.

Monte-Carlo simulations involve repeating a simulation process, using in each simulation a particular set of values of the random variables generated in accordance with the corresponding probability distributions. By repeating the process, a sample of solutions, each corresponding to a different simulation is similar to a sample of experimental observations. Therefore, the results of Monte Carlo simulations may be treated statistically; such results may also be presented in the form of histograms, and methods of statistical estimation and inference are applicable. For these reasons, Monte Carlo is also a sampling technique, and as such shares the same problems of sampling theory; namely, the results are also subject to sampling errors. Generally, therefore, Monte Carlo solutions from finite samples are not “exact” (unless the sample size is infinitely large). Monte-Carlo simulations, however, are often the only means of verifying or validating approximate analytical solution methods.