Encyclopaedia of Environmental Pollution

Vol. 2

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OF
ENVIRONMENTAL POLLUTION

ENVIRONMENTAL AIR POLLUTION

VOLUME - 2

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Preface

Within recent years attention has been drawn to the complexity of the problem of air pollution in large urban centres. Although information is being rapidly acquired on many constituents of the contaminants is still unknown. The agricultural revolution and industrialization have truely exacerbated the problems of pollution these having been well documented. But they indeed have been chronicled much earlier.

The major sources by for of air contaminants from the activities of man are the products of combustion released in ever-increasing quantities through the use of fuels domestic and industrial heating, power generation, transportation and other purpose. The dispertion of these pollutants in the atmosphere and their effects on terrestrial life as well as how to improve the quality are discussed throughout the book.

EDITORS

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Introduction

National air quality standards have been established for total suspended particulates (TSP), sulphur dioxide, carbon monoxide, photochemical oxidants, and nitrogen dioxide. These standards have been established for the short-term and long-term averaging periods by the 1970 Clean Air Act and its amendments. Table 1.1 identifies the ambient concentrations allowable for the various pollutants.

Further, non-degradation of air quality has become a politically possionate issue. No significant air quality deterioration regulations establish classes of air quality for various regions of the country. Regulations would not allow further degradation of the air quality within these regions beyond the limits set. Environmentalists believe these laws are necessary to prohibit air quality degradation beyond the national standards and to preserve the pure and pristine atmospheres of the national parks and similar areas. On the other hand, many feel this type of law would be too restrictive to industrial expansion and economic growth.

At the time of this writing Congress was still haggling over the issue. However, present pollution control technology can be applied in most cases to allow expansion into the pristine environments. The problem is economics.

TABLE 1.1
National Air Quality Standards for Pollutant Ambient Concentrations

Pollutant	Description	Pollutant Standard	
		Primary	Secondary
Total Suspended Particulates	Solid and liquid particles in the atmosphere including dust, smoke, mists, fumes and spray from many sources.	75$\mu g/m^3$, annual geometric mean; 260 $\mu g/m$, maximum 24-hour average	60 $\mu g/m^3$, annual geometric mean; 180 $\mu g/m$, maximum 24-hour average
Sulphur Dioxide	Heavy, pungent, colourless gas formed from combustion of coal, oil and other.	80 $\mu g/m^3$ (0.03 ppm), annual arithmetic mean; 365 $\mu g/m^3$ (0.14 ppm), maximum 24-hour average	1300 $\mu g/m^3$ maximum 8-hour average
Carbon Monoxide	Invisible, odourless gas formed from combustion of gasoline, coal, and other; largest man-made fraction comes from automobiles.	10 mg/m^3 (9 ppm), maximum 8-hour average; 40 mg/m (35 ppm) maximum 1-hour average	Same as primary
Photochemical Oxidants (as O_1)	Pungent, colourless toxic gas; one component of photochemical smog.	160 $\mu g/m^3$ (0.08 ppm), maximum 1-hour average	Same as primary
Nitrogen Dioxide	Brown, toxic gas formed from fuel combustion. Under certain conditions, it may be associated with ozone production.	100 $\mu g/m^3$ (0.05 ppm), annual arithmetic mean	Same as primary

Atmospheric Processes

The atmosphere has always been used as a sink for pollution. It has many natural pollutant removal mechanisms including: foliar absorption, soil absorption, absorption by natural water bodies, absorption by natural rock, rainout and washout (scavenging), and ambient chemical reactions. These processes are dependent on the conditions of the atmosphere (meteorology). Pollutant transfer and reactions are a function of the atmospheric dispersion process because in most instances it is the prime pollutant transport mechanism enabling the above removal processes to occur.

Atmospheric dispersion of a pollutant is primarily dependent on meteorological conditions and pollutant stack emission parameters such as gas velocity, temperature and molecular weight. Thus, the air quality of a region is greatly influenced by meteorological conditions. Weather parameters such as ambient temperature, wind speed, cloud cover, insolation, and inclement conditions (rain, snow, hail, etc.) can determine the impact severity of atmospheric pollutants. Obviously, the weather of most areas is well defined over long periods of time, but the daily or even monthly forecasts prove to be very difficult.

Therefore, in the selection of a plant site the planner usually considers the climatology of the area. The atmospheric emission rates of the proposed plant are assessed as influenced by this climatology, but taking into account the worst possible cases. In this manner stacks can be designed and control devices considered and implemented, if necessary, to lessen the air quality impact of the plant.

The location of the plant within an area can be dependent on the local wind directions. For example, residential areas may lie downwind of the plant, in line with the prevailing wind direction. A more suitable site might have to be considered to reduce the air impact of the plant. Further, in the planning of the plant, consideration should be given to local, state and federal air pollution authorities which may require a shut-down or curtailment of plant emission activities during times of extreme air pollution problems. These backup procedures should be discussed in detail in the EIS.

In the description of meteorological conditions for the EIS the data used are usually obtained from the local airport weather station. However, localized weather conditions can in some instances be very different from those of weather stations just 5 miles away. This condition can be caused by variations in topography, buildings, urban areas (heat islands) and land forms.

Meteorological Conditions of air Dispersion

The wind is the primary atmospheric transport mechanism. The winds of the earth are the result of the pressure differences induced by the heating and cooling of the atmosphere by the sun. The rotation of the earth also imparts a motion on the atmosphere combining to produce a localized wind rose. The wind rose of a region is its characteristic wind patterns with respect to wind speed and wind direction.

The wind roses of a region can be for monthly, seasonal or annual weather conditions. A typical monthly wind rose of Cincinnati. Note the south to southwest wind is the dominant wind direction, the "prevailing wind direction".

The wind speed also varies with height, and this is known as the wind shear. The wind speed variation with increased elevation. It further shows a gradient wind variation with topography and population densities. Mountains, hills, trees, buildings and other obstructions can divert wind patterns, increase atmospheric turbulence, and affect general atmospheric stability.

The atmospheric stability is related to the rising and falling of volumes of air. It is a function of temperature gradient, atmospheric tubulence, wind speed, insolation, cloud cover, and other weather conditions (rain, hail, snow).

In general, the atmospheric stability is determined by the atmospheric thermal gradient. The dry adiabatic lapse rate, or neutral stability has a temperature gradient of $-1°C/100$ meters, or temperatures decrease 1°C for every 100 meters. This condition is such that a volume of pollutant in air would neither gain nor lose buoyancy upon emission. Unstable conditions with lapse rates greater than $-1°C/100$ meters add to the buoyancy of an emission, and stable conditions or inversions with lapse rates less than $-1°C/00$ meters tend to inhibit vertical motion of the pollutant gases (plume).

The actual region of the atmosphere where pollutant emissions and ambient parameters can intermingle is confined to the mixing layer. The mixing layer is the region of the atmosphere capped by a layer of warm air which inhibits any movement past it in the upward direction by cooler air. This lid effect with a temperature versus elevation diagram. The height of this mixing layer can greatly affect the dispersion process. Low mixing layer heights, confining dispersion and trapping pollutants can result in air pollution emergencies and in many cases sickness and death.

Physical Dispersion

Pollutants exit a stack in the form of a flowing cloud or plume. The configuration of the plume is a function of the atmospheric stability which, in turn, affects the manner and amount of dispersion. Atmospheres that are nearly neutral produce a coning plume. These conditions do not greatly influence the motion of the plume. Unstable atmospheres tend to cause the plume to be buoyed up and down and break. This is known as a looping plume. A fanning plume is characteristic of an extremely stable or inversion condition inhibiting vertical motion, resulting in a "pencil-like" plume that can be continuous for ever 50 miles. When the mixing layer is very low and/or stack exiting conditions right (high velocity and temperature), the mixing layer may be penetrated. No pollutants will penetrate back down through this layer, thus a lofting plume is formed. On the other hand, a low mixing height could result in no upward penetration and a build-up of pollutants beneath this layer.

The writer of an EIS must be aware of the proposed project's regional as well as local meteorological conditions and the effects they would have on dispersion. He must be cognizant of the various plume types and the various weather conditions that will produce them.

A power plant built in the southwest sector of the country where atmospheric stabilities are usually extremely stable will produce fanning plumes stretching for almost 100 miles. However, construction in the Los Angeles area would cause concern about possible fumigations.

Depending on a region's meteorological conditions, process alternatives to effect different stack emission parameters may have to be considered. Highly stable atmospheres or inversions can trap the waste gases below a mass of relatively hot air limiting dispersion and allowing pollutant concentration to build up. These weather conditions, continuing over metropolitan areas for a period of days, have caused many illnesses and deaths. However, of usual concern to governmental agencies is the maximum ground level concentrations (glc) produced by an emission source, and for the short term these normally occur under unstable atmospheres.

Under unstable atmospheres, it is more likely for atmospheric turbulence and crosswinds to carry the plume to the ground. Critical glc's can usually be predicted based on an unstable atmosphere allowing the EIS writer to determine the proposed project's worst cases and the short-term effects. For any given day the atmospheric stability can usually be obtained from the local weather bureau or estimated from Pasquill's commonly used chart given as Table 1.2. This chart can be used in the air quality prediction methods we present.

Since the EIS must assess the impact on air quality of a proposed project, a determination of the effects of stack emissions must be made. This is accomplished through the use of mathematical models of the dispersion process. The dispersion process will be discussed briefly to give the reader a better understanding of the many parameters and interactions involved, and to get a general feel for the limits of these models.

The Dispersion Process

Dispersion from an elevated source (stack) is produced by the mixing and dilution of waste gases with the atmosphere. This is generally accomplished by the turbulent action of the exiting gases, and the crosswind, eddy currents, wind shear, etc.

At the effective stack height, pollutant gases are diluted

TABLE 1.2

The Pasquill Chart for Determining at Atmospheric Stability Class

Atmospheric Stability Class	Class Description
A	Extremely unstable
B	Unstable
C	Slightly unstable
D[a]	Neutral
E	Slightly stable
F	Stable to extremely stable

Surface Wind Speed (at 10 m), m sec^{-1}	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or ⩾4/8 Low Cloud	⩽3/8 Cloud
	Strong	Moderate	Slight		
<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

(a) The neutral class, D, should be assumed for overcast conditions during day or night.

further by increased wind speeds. Higher wind speeds make available more volumes of air to be mixed with the plume in a shorter time period. However, higher wind speeds also tend to "bend" a plume, retarding its vertical motion and increasing downwind pollutant concentrations. Ground level concentrations are greater for higher wind speeds since the plume is forced to ground level before the pollutants can be dispersed over a much broader region and atmospheric volume. Thus, in order to reduce the environmental impact of an emission, there is the need to increase the area over which a pollutant is dispersed as well as to kep the emissions from harming surrounding structures—resulting in tall stacks and the desirability for large plume rises.

The calculation methods to predict ambient pollutant concentrations which we will offer are based on a two-step process for dispersion. First, the pollutant gases from a stack rise as a result of their own conditions of release, and then they are dispersed in accordance with a Gaussian or normal distribution.

Meteorology plays an important role in determining dispersion and the height to which pollutants rise. Wind speed, wind shear and eddy current influence the interaction between plume and atmosphere. Ambient temperatures affect the buoyancy of a plume. However, in order to make equations of a mathematical model solvable, the plume rise is assumed to be a function of the emission conditions of release, and many other effects are considered insignificant.

Short-Term Effects

The calculation methods presented first are for the prediction of short-term effects. Short-term pollutant glc's are predicted for time periods of 24 hours or less. Under these conditions meteorology is assumed to remain constant for the calculated time period.

Plume Rise

The vertical motion of the plume to the height where it becomes horizontal is known as the plume rise. The plume rise is assumed to be a function primarily of the emission conditions of release (i.e., velocity and temperature characteristics). A velocity in the vertical plane gives the gases an upward momentum causing the plume to rise until atmospheric turbulence disrupts the integrity of the plume. At this point the plume ceases to rise. This is known as the momentum plume rise.

Stack gas exiting temperatures are usually much greater than ambient making them less dense than the surrounding air. This difference in densities gives the gases a buoyancey allowing the plume to rise until it is cooled by the atmosphere, reducing the density differential to zero. This is known as the thermal plume rise.

The momentum and thermal plume rises combine to produce the plume rise of an emission. These effects are not independent: gases with a high exit velocity are cooled faster as a result of normal atmospheric mixing of the plume. The thermal buoyancy contribution to plume rise can therefore, be lessened by increased exit velocities. Low exit velocities can cause the plume to become trapped in the turbulent wake along the side of the stack, and fall rapidly to the ground (fumigation). Fumigation can usually be prevented by keeping the emission velocity greater than 10 meters/second. An emission velocity that is one and one-half times greater than the atmospheric crosswind is generally accepted as a safety factor to prevent fumigation.

In many calculation methods, the momentum contributions to plume rise are considered negligible as compared to the thermal plume rise and are disregarded.

Effective Stack Height

The importance of plume rise is that it determines the effective stack height, or the height at which most calculation procedures assume dispersion to begin. The plume rise added to the actual height of the stack is the effective stack height.

$$h = h_s + \triangle h$$

At the effective stack height the dispersion of pollutants are assumed spread out as a Gaussian distribution. The basic dispersion equation considers a continuously emitting point source emanating through a co-ordinate system with its origin at the base of the source as shown in Fig 1.1.

Emissions of gases or particles less than 20 microns (larger particles settle more quickly due to gravitational effects) disperse with an origin and plume conterline at the effective stack height. They then spread out in the horizontal and vertical planes. Pollutant concentrations are greatest within one standard deviation of the plume centerline. Thus, the determination of the value of these standard deviations is an important factor in calculating ambient concentrations.

The standard devilations in the vertical a_z and in the hori-

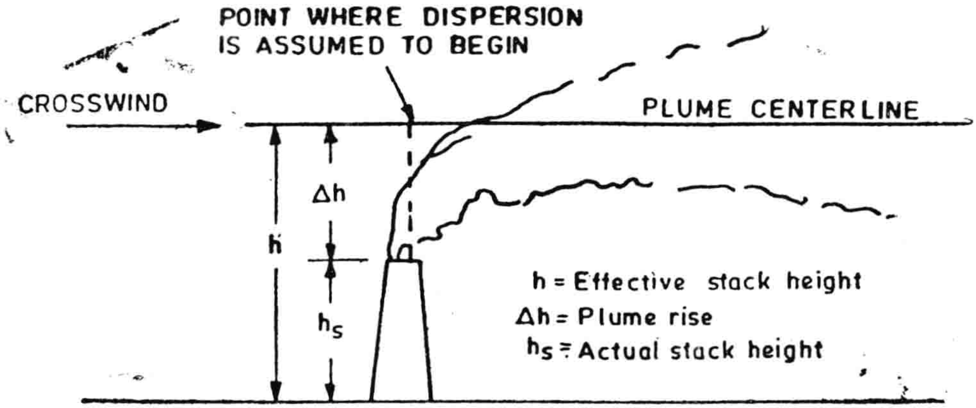

Fig 1.1. At the effective stack height most calculation procedures assume dispersion to begin.

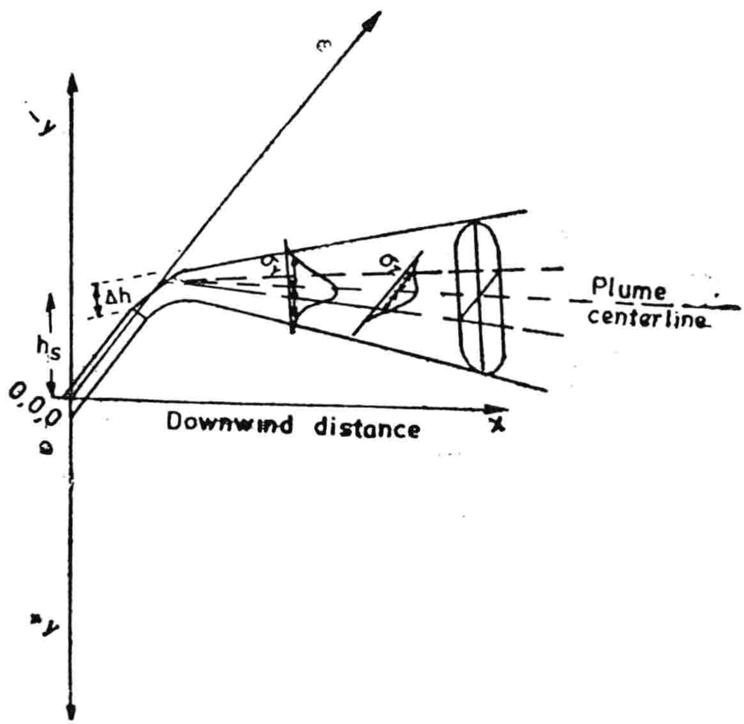

Fig 1.2. Coordinate system of a Gaussian distribution plume dispersal.

zontal a_y of the dispersing plume along the centerline are functions of meteorological conditions and downwind distances. These dispersion parameters and the effective stack height can be calculated in a number of ways, using various empirical constants. Each manner of calculating these parameters, σ_y, σ_z and Δh defines a different calculation method without disrupting the basic Gaussian calculation procedures. These methods will now be discussed.

The basic dispersion equation to calculate glc's directly downwind from a point source is as follows:

$$X = \frac{Q}{\pi \bar{u}_s \sigma_y \sigma_z} \exp. \left[\frac{h}{2\sigma_z} \right]$$

where X = ground level concentration (gm/m^3)

Q = pollutant exit rate (gm/sec)

σ_y' σ_z = horizontal and vertical plume standard deviations/m

$\bar{u}_s$ = mean wind speed at height of stack (m/sec)

h = effective stack height (m)

x = downwind distance (m)

y = crosswind distance (m)

The maximum glc is of importance to the EIS writer in determining the proposed project's compliance with governmental regulations and the worst case with regard to environmental impacts. It can be calculated as follows:

$$X_{max} = \frac{20}{e \pi \bar{u}_s h^2} \frac{\sigma_z}{\sigma_y}$$

The three commonly used dispersion calculation methods for the prediction of ground level concentration are based on the above equation. The variance in each method is the calculation of plume rise, Δh, and the horizontal and vertical plume dispersion parameters. These methods are:

1. the ASME plume rise equation and the ASME dispersion parameters;