Chapter 7

Meteorology and Air Pollution

The earth's atmosphere is about 100 miles deep.

That thickness and volume sometimes are suggested to be enough to dilute all of the chemicals and particles thrown into it.

However, 95% of this air mass is within 12 miles of the earth's surface.

This 12-mile depth contains the air we breathe as well as the pollutants we emit.

This layer, called the troposphere, is where we have our weather and air pollution problems.

Weather patterns determine how air contaminants are dispersed and move through the troposphere, and thus determine the concentration of a particular pollutant that is breathed or the amount deposited on vegetation.

An air pollution problem involves three parts:

- The pollution source
- The movement or dispersion of the pollutant
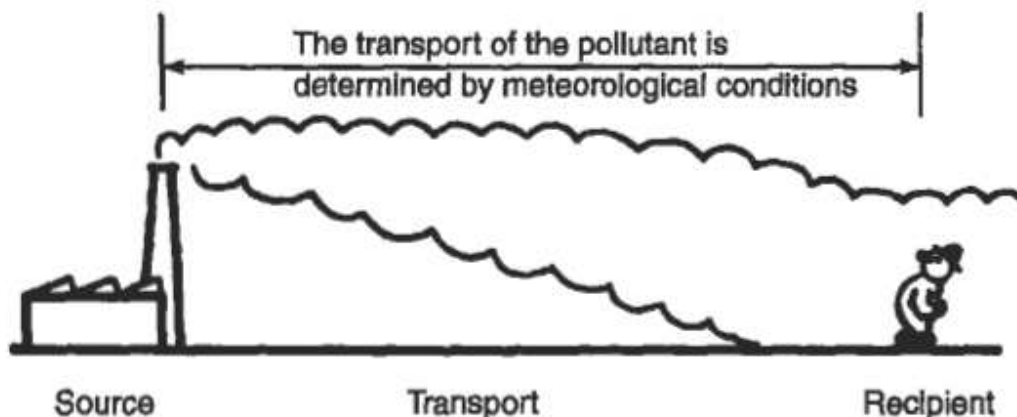- The recipient

Figure 1. Meteorology of air pollutants.

This chapter concerns itself with the transport mechanism: how the pollutants travel through the atmosphere.

The environmental engineer should be conversant enough with some basic meteorology to be able to predict the dispersion of air pollutants.

BASIC METEOROLOGY

Pollutants circulate the same way the air in the troposphere circulates.

Air movement is caused by solar radiation and the irregular shape of the earth and its surface, which causes unequal absorption of heat by the earth's surface and atmosphere.

This differential heating and unequal absorption creates a dynamic system.

The dynamic thermal system of the earth's atmosphere also yields differences in barometric pressure, associated with low-pressure systems with both hot and cold weather fronts.

Air movement around low-pressure fronts in the Northern Hemisphere is counterclockwise and vertical winds are upward, where condensation and precipitation take place.

High-pressure systems bring sunny and calm weather – stable atmospheric conditions - with winds (in the Northern Hemisphere) spiraling clockwise and downward.

Low- and high-pressure systems, commonly called cyclones and anticyclones, are illustrated in Fig. 2.

Anticyclones are weather patterns of high stability, in which dispersion of pollutants is poor, and are often precursors to air pollution episodes.

The high-pressure area indicates a region of stable air, where pollutants build up and do not disperse.
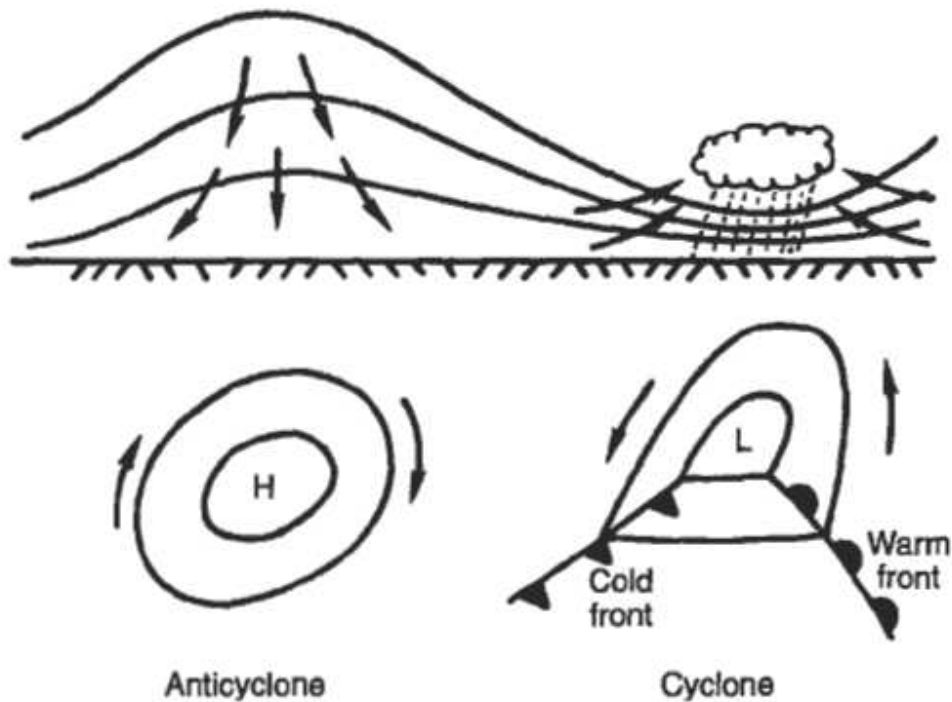
Figure 2. Anticyclone and cyclone.

Air quality management involves both control of air pollution sources and effective dispersion of pollutants in the atmosphere.

HORIZONTAL DISPERSION OF POLLUTANTS

The earth receives light energy at high frequency from the sun and converts this to heat energy at low frequency, which is then radiated back into space.

Heat is transferred from the earth's surface by radiation, conduction, and convection.

Radiation is direct transfer of energy and has little effect on the atmosphere.

Conduction is the transfer of heat by physical contact (the atmosphere is a poor conductor since the air molecules are relatively far apart).

Convection is transfer of heat by movement of warm air masses.

Solar radiation warms the earth and thus the air above it. This heating is most effective at the equator and least at the poles.

The warmer, less dense air rises at the equator and cools, becomes more dense, and sinks at the poles.

If the earth did not rotate then the surface wind pattern would be from the poles to the equator.

However, the rotation of the earth continually presents new surfaces to be warmed, so that a horizontal air pressure gradient exists as well as the vertical pressure gradient.

The resulting motion of the air creates a pattern of winds around the globe, as shown by Fig. 18-3.
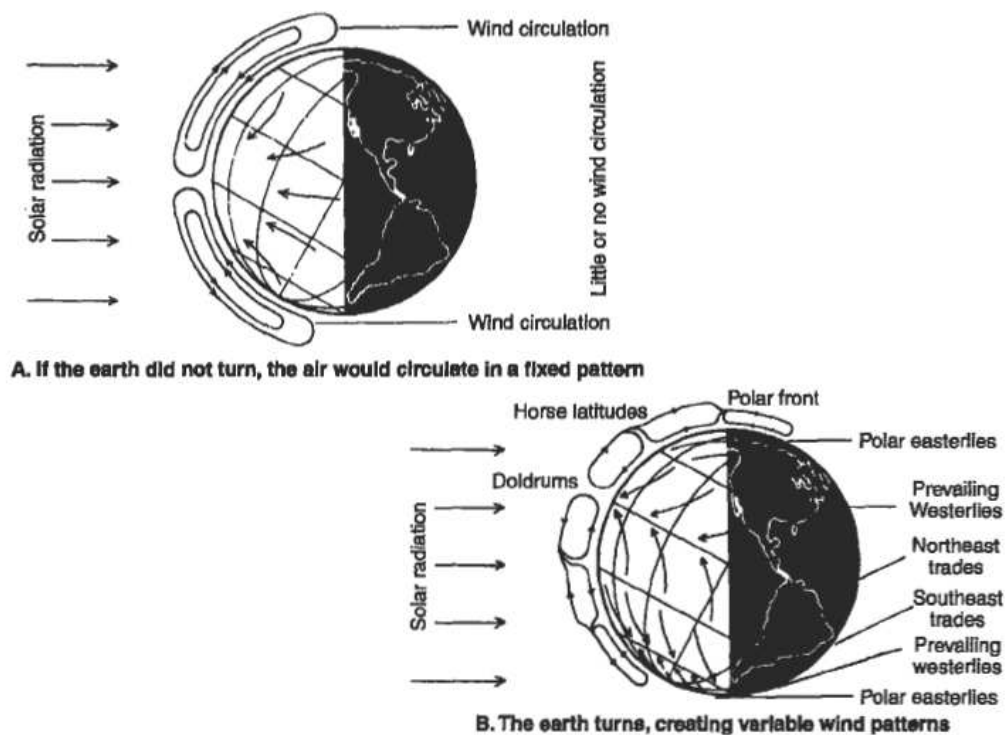

Figure 3. Global wind patterns.

Seasonal and local temperature, pressure and cloud conditions, and local topography complicate the picture.

Land masses heat and cool faster than water so that shoreline winds blow out to sea at night and inland during the day.

Valley winds result from cooling of air high on mountain slopes.

In cities, brick and concrete buildings absorb heat during the day and radiate it at night, creating a heat island (Fig. 4), which sets up a self-contained circulation called a haze hood from which pollutants cannot escape.
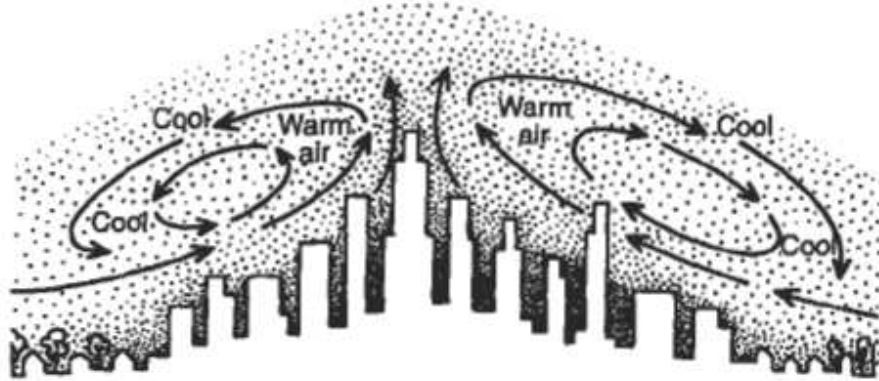

Figure 4. Heat island formed over a city.

Horizontal wind motion is measured as wind velocity. Wind velocity data are plotted as a wind rose, a graphic picture of wind velocities and the direction from which the wind came. The wind rose in Fig. 5 shows that the prevailing winds were from the southwest.
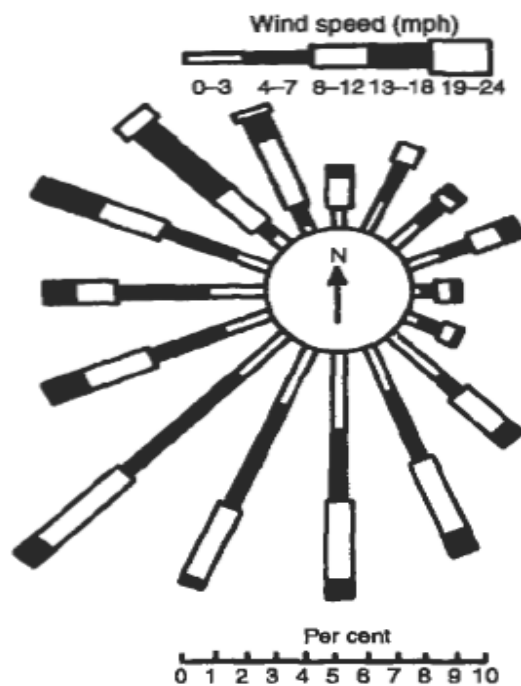

Figure 5. Typical wind rose.

The three features of a wind rose are:

1. The orientation of each segment, which shows the direction from which the wind came
2. The width of each segment, which is proportional to the wind speed
3. The length of each segment, which is proportional to the percent of time that wind at that particular speed was coming from that particular direction.

Air pollution enforcement engineers sometimes use a pollution rose, a variation of a wind rose in which winds are plotted only on days when the air contamination level exceeds a given amount.

Figure 6 shows pollution roses at three points plotted only for days when the SO_2 level exceeded 250 µg/m3.

Figure 6. Pollution roses for SO2 concentrations greater than 250 pg/m3. The four chemical plants are the suspected sources, but the roses clearly point to Plant 3, identifying it as the primary culprit.

Note that because the roses indicate the directions from which the wind is coming the apparent primary pollution source is plant 3.

Wind is probably the most important meteorological factor in the movement and dispersion of air pollutants, or, in simple terms, pollutants move predominantly downwind.

VERTICAL DISPERSION OF POLLUTANTS

As a parcel of air in the earth's atmosphere rises through the atmosphere, it experiences decreasing pressure and thus expands.

This expansion lowers the temperature of the air parcel, and therefore the air cools as it rises.

The rate at which dry air cools as it rises is called the dry adiabatic lapse rate and is independent of the ambient air temperature.

The term "adiabatic" means that there is no heat exchange between the rising parcel of air under consideration and the surrounding air.

The dry adiabatic lapse rate may be calculated from basic physical principles.

$$dT/dz|_{\text{dry-adiabatic}} = -9.8°C/km,$$

where T = temperature and z = altitude.

The actual measured rate at which air cools as it rises is called the ambient or prevailing lapse rate.

The relationships between the ambient lapse rate and the dry adiabatic lapse rate essentially determine the stability of the air and the speed with which pollutants will disperse.
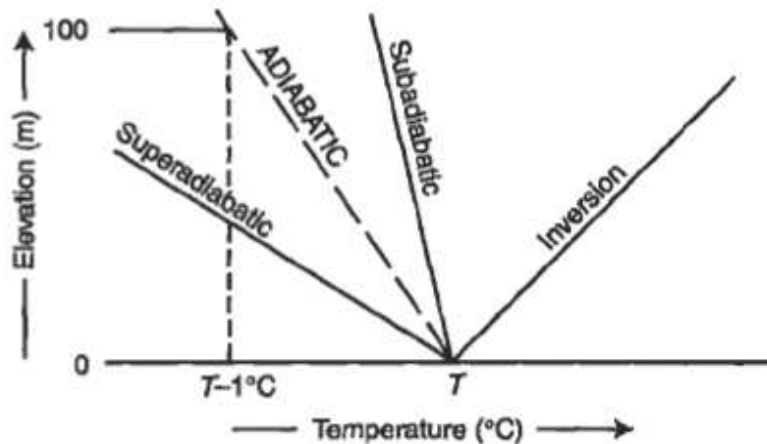
These relationships are shown in Fig. 7.

Figure 7. Ambient lapse rates and the dry adiabatic lapse rate.

When the ambient lapse rate is exactly the same as the dry adiabatic lapse rate, the atmosphere has neutral stability.

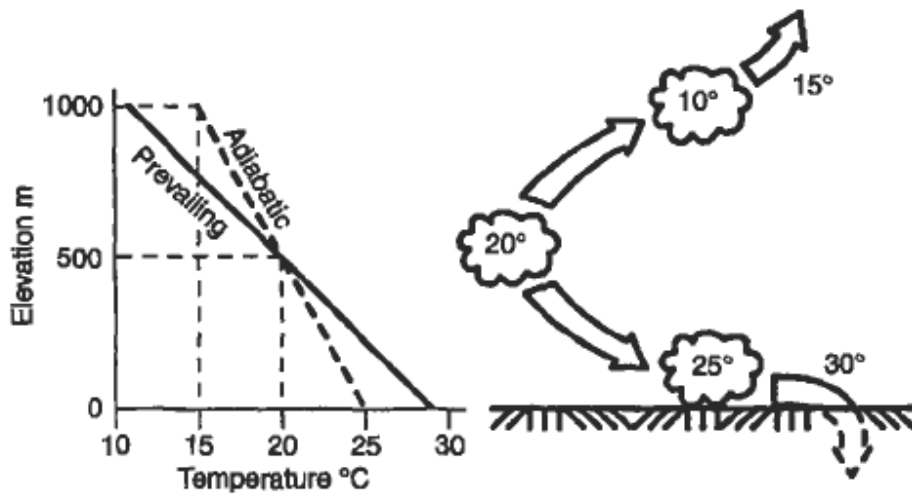Superadiabatic conditions prevail when the air temperature drops more than $9.8^{\circ}C/Km$ ($1^{\circ}C/100m$).

Subadiabatic conditions prevail when the air temperature drops at a rate less than $9.8^{\circ}C/Km$.

A special case of subadiabatic conditions is the temperature inversion, when the air temperature actually increases with altitude and a layer of warm air exists over a layer of cold air.
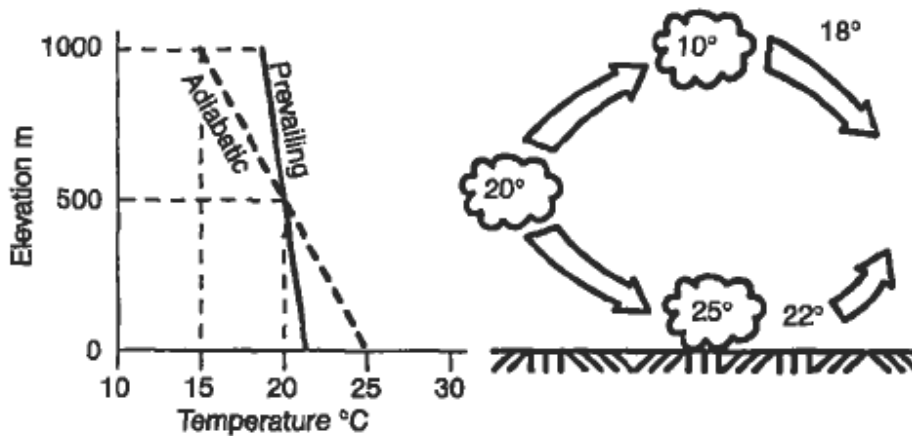
Superadiabatic atmospheric conditions are unstable and favor dispersion; subadiabatic conditions are stable and result in poor dispersion; inversions are extremely stable and trap pollutants, inhibiting dispersion.

These conditions may be illustrated by the following example, illustrated in Fig. 8:

A. Super-adiabatic conditions (unstable)

B. Sub-adiabatic conditions (stable)

Figure 8. Stability and vertical air movement.

The air temperature at an elevation of 500 m is 20°C, and the atmosphere is superadiabatic, the ground level temperature is 30°C and the temperature at an elevation of 1 km is 10°C.

The (superadiabatic) ambient lapse rate is -20°C/km.

If a parcel of air at 500 m moves up adiabatically to 1 km, what will be its temperature? According to the dry adiabatic lapse rate of - 9.8^{o}C/Km the air parcel would cool by 4.9 ^{o}C to about 15°C.

However, the temperature at 1 km is not 15°C but 10°C. Our air parcel is 5°C warmer than the surrounding air and will continue to rise.

In short, under subadiabatic conditions, a rising parcel of air keeps right on going up. Similarly, if our parcel were displaced downward to, say, 250m, its temperature would increase by 2.5 °C to 22.5 °C.

The ambient temperature at 250 m, however, is 25 °C, so that our parcel of air is now cooler than the surrounding air and keeps on sinking.

There is no tendency to stabilize; conditions favor instability.

Now let us suppose that the ground level temperature is 22 °C, and the temperature at an elevation of 1 km is 15°C.

The (subadiabatic) ambient lapse rate is now -7 °C/Km.

If our parcel of air at 500 m moves up adiabatically to 1 km, its temperature would again drop by 4.9 °C to about 15°C, the same as the temperature of the surrounding air at 1 km.

Our air parcel would cease rising, since it would be at the same density as the surrounding air.

If the parcel were to sink to 250 m, its temperature would again be 22.5 °C, and the ambient temperature would be a little more than 20°C.

The air parcel is slightly warmer than the surrounding air and tends to rise back to where it was. In other words, its vertical motion is damped, and it tends to become stabilized, subadiabatic conditions favor stability and limit vertical mixing.

Figure 9 is an actual temperature sounding for Los Angeles. Note the beginning of an inversion at about 1000 ft that puts an effective cap on the city and holds in the air pollution.

This type of inversion is called a subsidence inversion, caused by a large mass of warm air subsiding over a city.
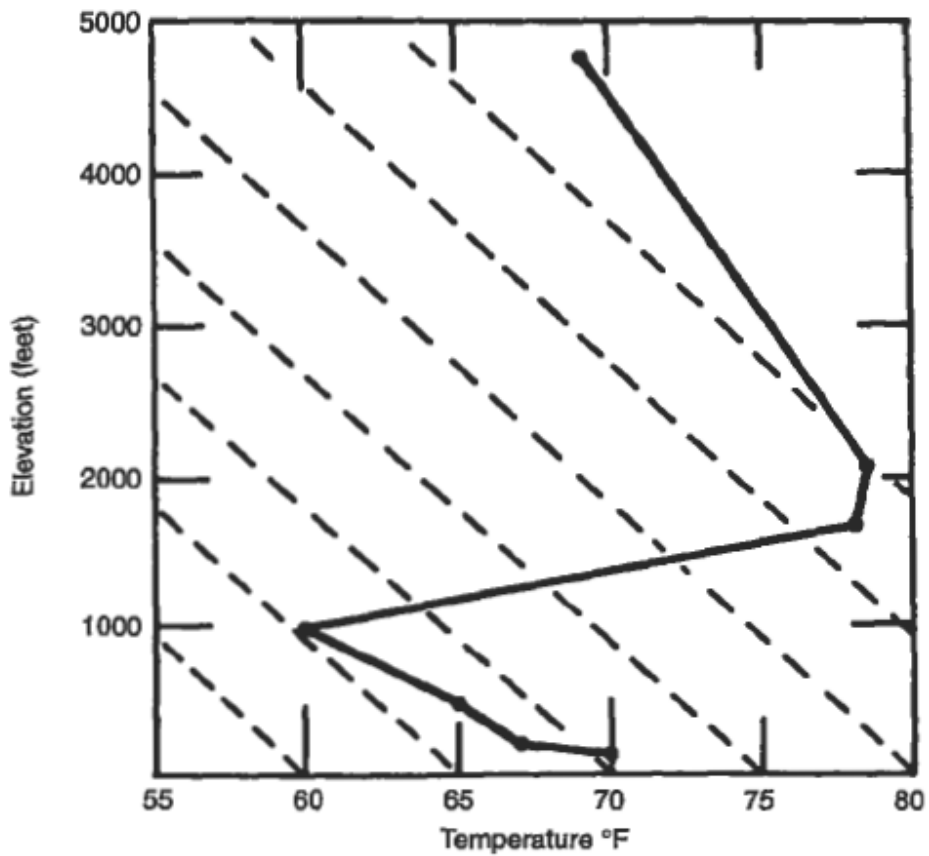
Figure 9. Temperature sounding for Los Angeles, 4 PM, October 1962. The dotted lines show the dry adiabatic lapse rate.

A more common type is the radiation inversion, caused by radiation of heat from the earth at night. As heat is radiated, the earth and the air closest to it cool, and this cold air is trapped under the warm air above it (Fig. 10).
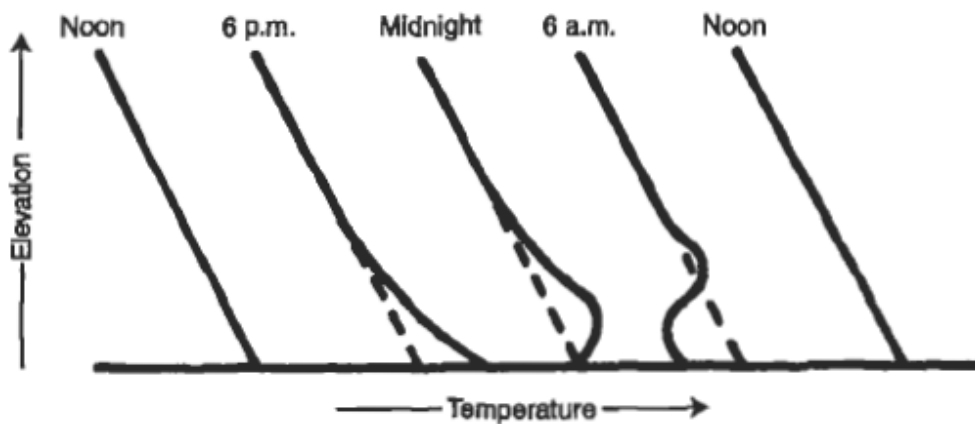

Figure 10. Typical ambient lapse rates during a sunny day and clear night.

Pollution emitted during the night is caught under the "inversion lid."

Atmospheric stability may often be recognized by the shapes of plumes emitted from smokestacks as seen in Figs. 11 and 12.
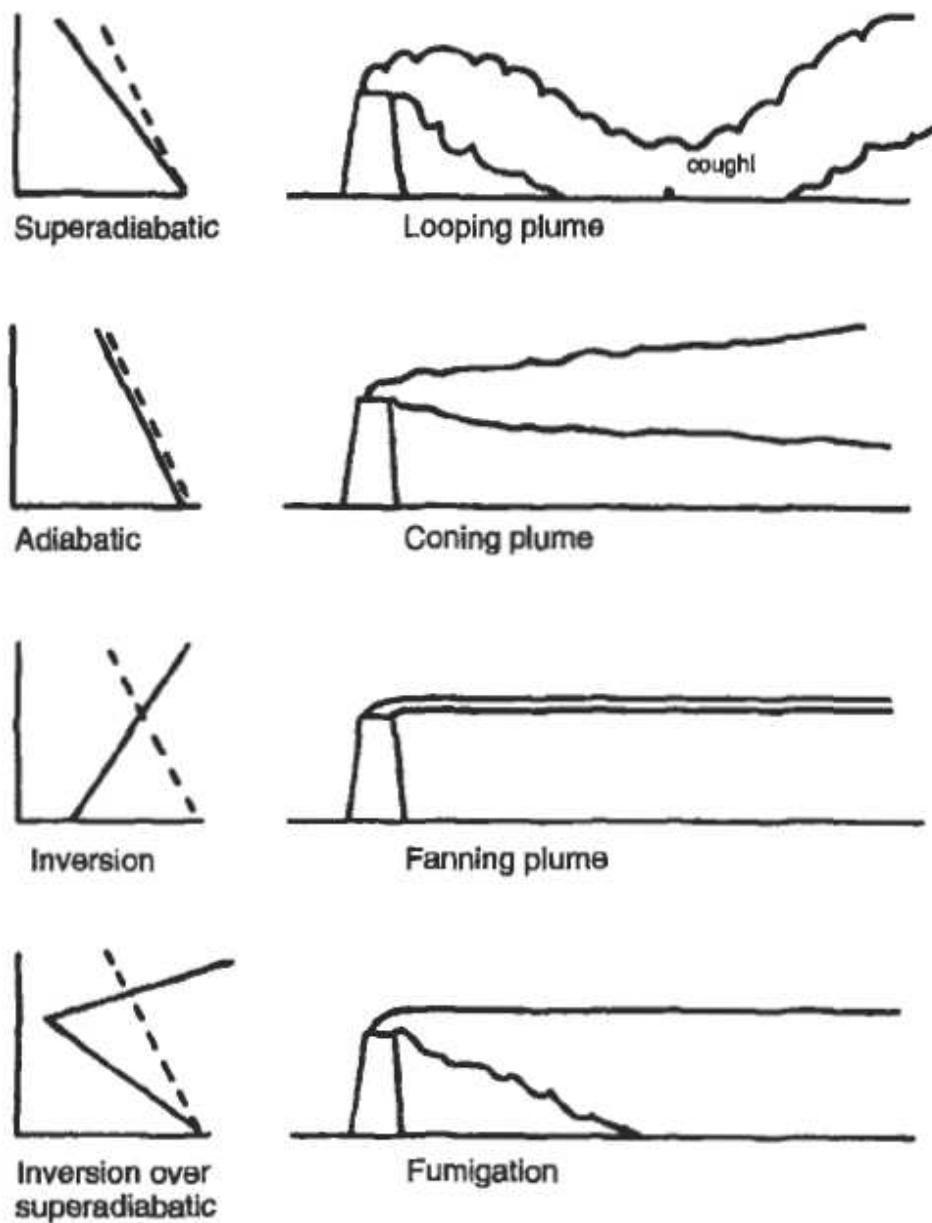

Figure 11. Plume shapes and atmospheric stability.

Figure 12. Iron oxide dust looping plume from a steel mill

Neutral stability conditions usually result in coning plumes, while unstable (superadiabatic) conditions result in a highly dispersive looping plume.

Under stable (subadiabatic) conditions, the funning plume tends to spread out in a single flat layer.

One potentially serious condition is called fumigation, in which pollutants are caught under an inversion and are mixed owing to strong lapse rate.

A looping plume also produces high ground-level concentrations as the plume touches the ground.

Assuming adiabatic conditions in a plume allows estimation of how far it will rise or sink, and what type of plume it will be during any given atmospheric temperature condition, as illustrated by Example 1.

EXAMPLE 1.
A stack l00 m tall emits a plume whose temperature is 20°C. The temperature at the ground is 19°C. The ambient lapse rate is -4.5 °C /km up to an altitude of 200 m. Above this the ambient lapse rate is +20°C /km. Assuming perfectly adiabatic conditions, how high will the plume rise and what type of plume will it be?
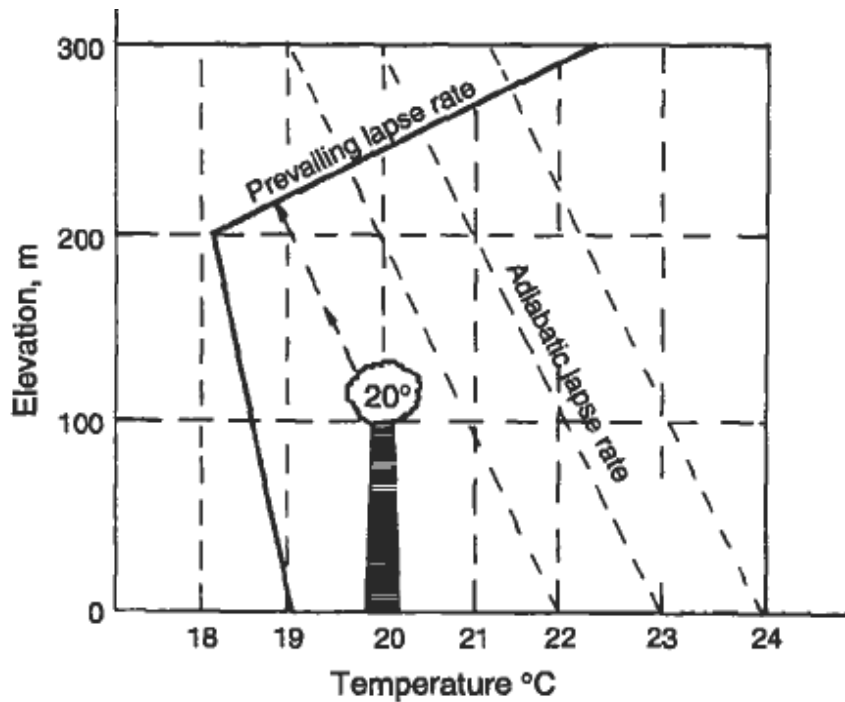Figure 13 shows the various lapse rates and temperatures.

Figure 13. Atmospheric conditions in Example 1.

The plume is assumed to cool at the dry adiabatic lapse rate 10°C km. The ambient lapse rate below 200 m is subadiabatic, the surrounding air is cooler than the plume, so it rises, and cools as it rises.

At 225 m, the plume has cooled to 18.7°C, but the ambient air is at this temperature also, and the plume ceases to rise.

Below 225 m, the plume would have been slightly coning. It would not have penetrated 225 m.

Effect of Water in the Atmosphere

The dry adiabatic lapse rate is characteristic of dry air.

Water in the air will condense or evaporate, and in doing so will release or absorb heat, respectively, making calculations of the lapse rate and atmospheric stability complicated.

In general, as a parcel of air rises, the water vapor in that parcel will condense and heat will be released.

The rising air will therefore cool more slowly as it rises; the wet adiabatic lapse rate will in general be less negative than the dry adiabatic lapse rate.

The wet adiabatic lapse rate has been observed to vary between -6.5 and -3.5°C /Km.

Water in the atmosphere affects air quality in other ways as well.

Fogs are formed when moist air cools and the moisture condenses.

Aerosols provide the condensation nuclei, so that fogs tend to occur more frequently in urban areas.

Serious air pollution episodes are almost always accompanied by fog (remember that the roots of the word "smog" are "smoke" and "fog").

The tiny water droplets in fog participate in the conversion of SO_3 to H_2SO_4.

Fog sits in valleys and stabilizes inversions by preventing the sun from warming the valley floor, thus often prolonging air pollution episodes.

ATMOSPHERIC DISPERSION

Dispersion is the process by which contaminants move through the air and a plume spreads over a large area, thus reducing the concentration of the pollutants it contains.

The plume spreads both horizontally and vertically.

If it is a gaseous plume, the motion of the molecules follows the laws of gaseous diffusion.

The most commonly used model for the dispersion of gaseous air pollutants is the Gaussian model developed by Pasquill, in which gases dispersed in the atmosphere are assumed to exhibit ideal gas behavior.

The principles on which the model is based are:

- The predominant force in pollution transport is the wind; pollutants move predominantly downwind.

- The greatest concentration of pollutant molecules is along the plume center line.
- Molecules diffuse spontaneously from regions of higher concentration to regions of lower concentration.

- The pollutant is emitted continuously, and the emission and dispersion process is steady state.

Figure 14 shows the fundamental features of the Gaussian dispersion model, with the geometric arrangement of source, wind, and plume.
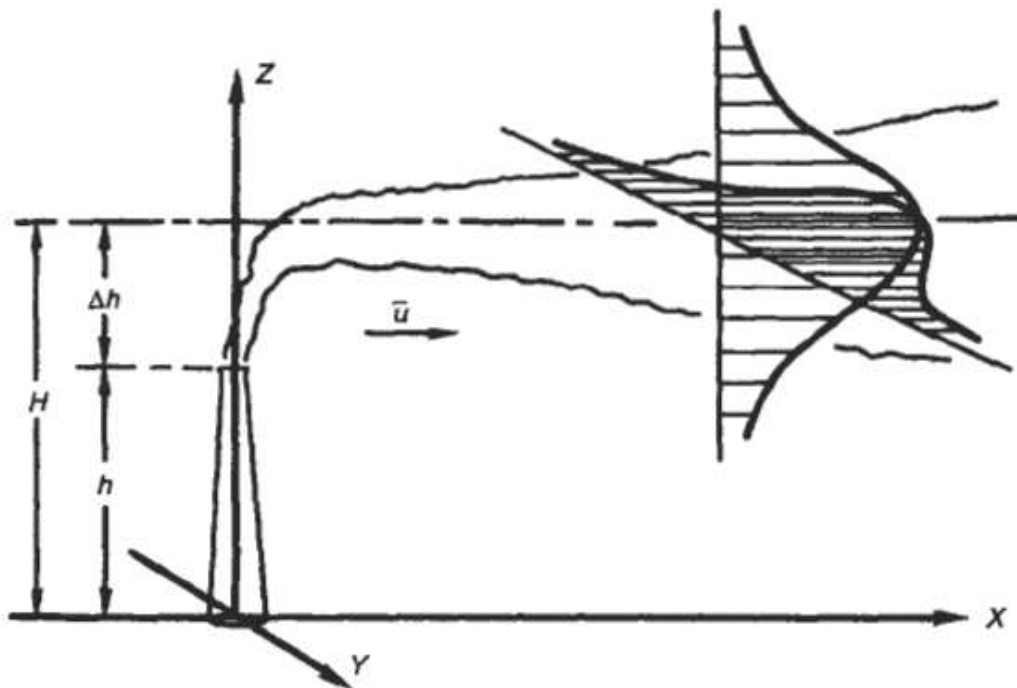

Figure 14. Gaussian dispersion model.

We can construct a Cartesian coordinate system with the emission source at the origin and the wind direction along the x axis. Lateral and vertical dispersions are along the y and z axes, respectively.

As the plume moves downwind, it spreads both laterally and vertically away from the plume centerline as the gas molecules move from higher to lower concentrations.

Cross sections of the pollutant concentration along both the y and the z axes thus have the shape of Gaussian curves, as shown in Fig. 14.

Since stack gases are generally emitted at temperatures higher than ambient, the buoyant plume will rise some distance before beginning to travel downwind.

The sum of this vertical travel distance and the geometric stack height is H, the effective stack height.

The source of the pollutant plume is, in effect, a source elevated above the ground at elevation

$$Z=H$$

and the downwind concentration emanating from this elevated source may be written

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left(\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)\right)$$

where
$C(x, y, z)$ is the concentration at some point in space with coordinates x, y, z,
Q = the emission rate of the pollution source (in g/s),
u = the average wind speed in (m/s) ,
σ_y = the standard deviation of the plume in the y direction (m), and
σ_z, = the standard deviation of the plume in the z direction (m).

The units of concentration are grams per cubic meter (g/m^3). Since pollution concentrations are usually measured at ground level, that is, for z = 0, the Eq. usually reduces to

$$C(x, y, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left(\exp\left(-\frac{(H)^2}{2\sigma_z^2}\right)\right)$$

This equation takes into account the reflection of gaseous pollutants from the surface of the ground.

We are usually interested in the greatest value of the ground level concentration in any direction, and this is the concentration along the plume centerline; that is, for y = 0.

In this case, the Eq. reduces to

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right)$$

Finally, for a source of emission at ground level, H = 0, and the ground level concentration of pollutant downwind along the plume centerline is given by

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z}$$

For a release above ground level the maximum downwind ground level concentration occurs along the plume centerline when the following condition is satisfied:

$$\sigma_z = \frac{H}{\sqrt{2}}.$$

The standard deviations σ_y, and σ_z, are measures of the plume spread in the crosswind (lateral) and vertical directions, respectively.

They depend on atmospheric stability and on distance from the source.

Atmospheric stability is classified in categories A through F, called stability classes. Table 1 shows the relationship between stability class, wind speed, and sunshine conditions.

Table 1. Atmospheric Stability under Various Conditions

Wind speed at 10 m (m/s)	Day Incoming solar radiation			Night Thin overcast	
	Strong	Moderate	Slight	1/2 low cloud	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	E
>6	C	D	D	D	D

Class A is the least stable; Class F is the most stable.

In terms of ambient lapse rates, Classes A, B, and C are associated with superadiabatic conditions; Class D with neutral conditions; and Classes E and F with subadiabatic conditions. A seventh, Class G, indicates conditions of extremely severe temperature inversion, but in considering frequency of occurrence is usually combined with Class F.

Urban and suburban populated areas rarely achieve stability greater than Class D, because of the heat island effect; stability classes E and F are found in rural and unpopulated areas.

Values for the lateral and vertical dispersion constants, σ_y, and σ_z, are given in Figs. 15 and 16.

Use of the figures is illustrated in the following Examples:

EXAMPLE 2

An oil pipeline leak results in emission of 100g/h of H_2S. On a very sunny summer day, with a wind speed of 3.0 m/s, what will be the concentration of H_2S 1.5 km directly downwind from the leak?

From Table 1, we may assume Class B stability. Then, from Fig. 15, at x = 1.5 km, σ_y is approximately 210m and, from Fig. 16, σ_z is approximately 160m, and

$$Q = 100 \text{ g/h} = 0.0278 \text{ g/s}.$$

Applying the Eq., we have

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z}$$

$$C(1500, 0, 0) = \frac{0.0278 \text{ g/s}}{\pi (3.0 \text{ m/s})(210 \text{ m})(160 \text{ m})} = 8.77 \times 10^{-8} \text{ g/m}^3 = 0.088 \, \mu\text{g/m}^3$$
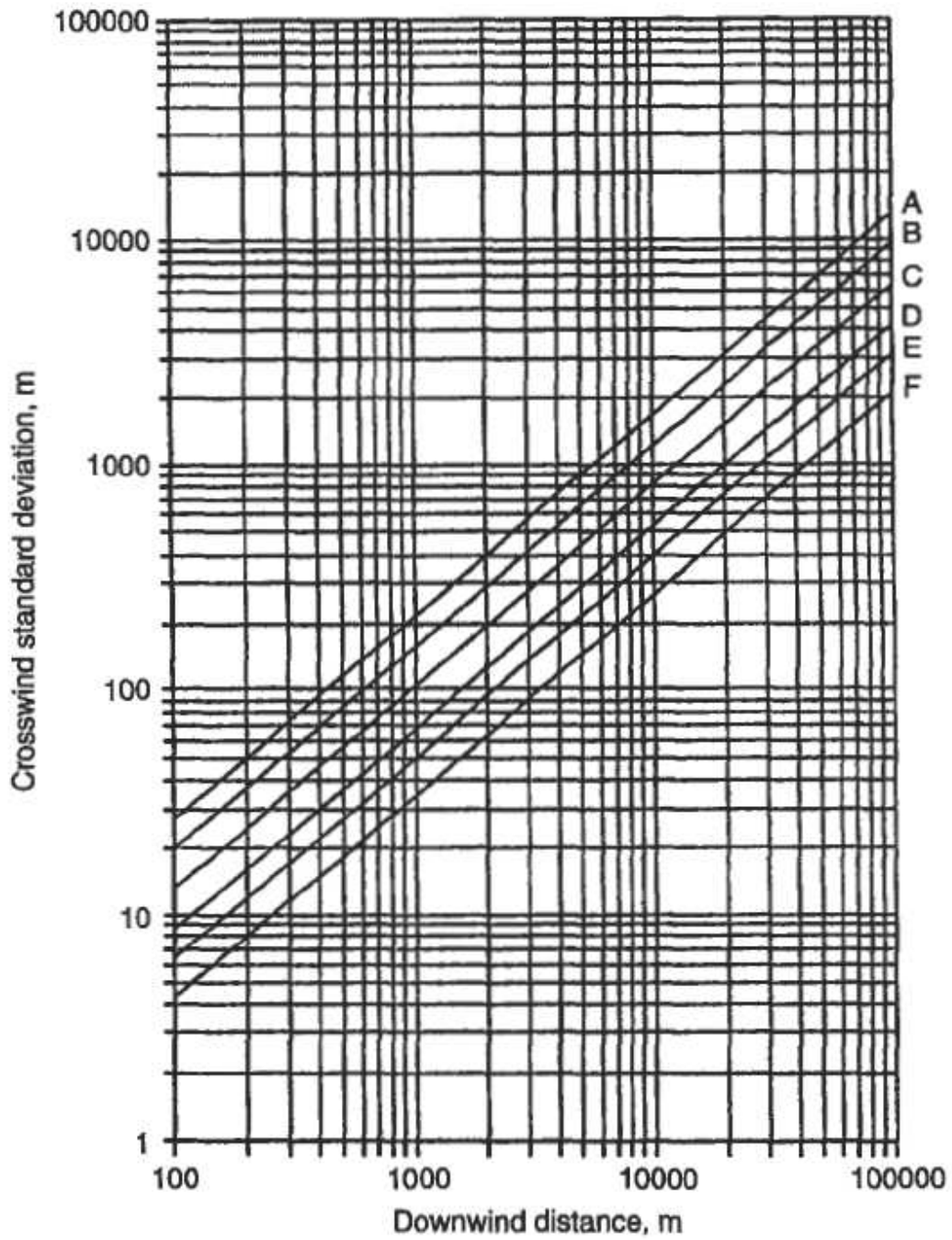
Figure 15. Standard deviation or dispersion coefficient, σ_y, in the crosswind direction as a function of downwind distance (Wark and Warner 1986).
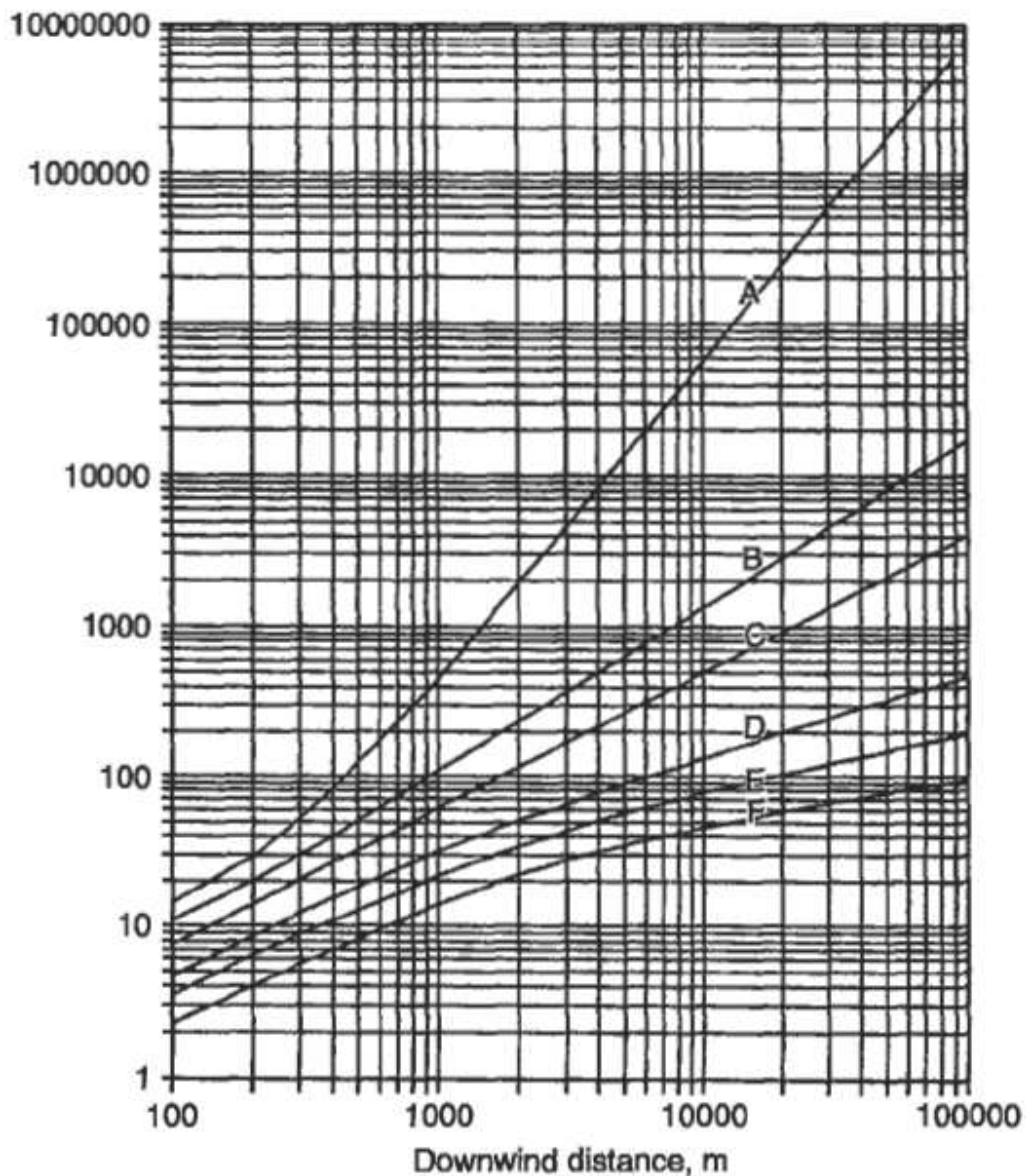
Figure 16. Standard deviation or dispersion coefficient, σ_z, in the vertical direction as a function of downwind distance (Wark and Warner 1986).

EXAMPLE 3

A coal-burning electric generating plant emits 1.1 kg/min of SO_2 from a stack with an effective height of 60m. On a thinly overcast evening, with a wind speed of 5.0 m/s , what will be the ground level concentration of SO_2 500 m directly downwind from the stack?

From Table 1, we may assume Class D stability. Then, from Fig. 15, at x = 0.5 km, σ_y is approximately 35 m and σ_z, is approximately 19 m, and

$$Q = 1.10 \text{ kg/min} = 18 \text{ g/s.}$$

In this problem, the release is elevated, and H = 60 m.

Applying the Eq., we have

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right)$$

$$C(0.5, 0, 0) = \frac{18 \text{ g/s}}{\pi (5 \text{ m/s})(35 \text{ m})(19 \text{ m})} \exp\left(\frac{-(60)^2}{2(19)^2}\right) = 11.8 \times 10^{-6} \text{ g/m}^3,$$

Variation of Wind Speed With Elevation

The model used so far assumes that the wind is uniform and unidirectional, and that its velocity can be estimated accurately.

These assumptions are not realistic:

Wind direction shifts and wind speed varies with time as well as with elevation.

The variation of wind speed with elevation can be approximated by a parabolic wind velocity profile.

That is, the wind speed u at an elevation h may be calculated from the measured wind speed u_o at a given elevation h_o using the relationship

$$u = u_0 \left(\frac{h}{h_0}\right)^n$$

The exponent n, called the stability parameter, is an empirically determined function of the atmospheric stability, and is given in Table 2.

Table 2. Relationship between the Stability Parameter and Atmospheric stability [a]

Stability condition	n
Large lapse rate (Classes A, B, C)	0.20
Zero or small lapse rate (Class D)	0.25
Moderate inversion (Class E)	0.33
Strong inversion (Classes F and G)	0.50

[a] From Wark and Warner (1986).

Wind is often measured in weather stations at an elevation of 10 m above ground level.

Effective Stack Height

The effective stack height is the height above ground at which the plume begins to travel downwind the effective release point of the pollutant and the origin of its dispersion.

A number of empirical models exist for calculating the plume rise h - the height above the stack to which the plume rises before dispersing downwind.

Three equations that give a reasonably accurate estimate of plume rise have been developed by Carson and Moses (1969) for different stability conditions.

For superadiabatic conditions

$$\Delta h = 3.47 \frac{V_s d}{u} + 5.15 \frac{Q_h^{0.5}}{u} ;$$

for neutral stability

$$\Delta h = 0.35 \frac{V_s d}{u} + 2.64 \frac{Q_h^{0.5}}{u}$$

and for subadiabatic conditions

$$\Delta h = -1.04 \frac{V_s d}{u} + 2.24 \frac{Q_h^{0.5}}{u}$$

where
V, = stack gas exit speed (in m/s),
d = stack diameter (in m), and
Q_h = heat emission rate from the stack (in kJ/s).

As before, length is in meters and time is in seconds, and the heat emission rate is measured in kilojoules per second.

EXAMPLE 4

A power plant has a stack with a diameter of 2 m and emits gases with a stack exit velocity of 15 m/s and a heat emission rate of 4,800 kJ/S. The wind speed is 5 m/s . Stability is neutral. Estimate the plume rise. If the stack has a geometric height of 40 m, what is the effective stack height?

$$\Delta h = 0.35 \frac{(15)(2)}{5} + 2.64 \frac{\sqrt{4800}}{5} = 38.7\,\text{m}$$

$$H = h_g + h$$

$$H = 40\,\text{m} + 38.7\,\text{m} = 78.7\,\text{m}.$$

The accuracy of plume rise and dispersion analysis is not very good.

Un calibrated models predict ambient concentrations to within an order of magnitude at best.

To ensure reasonable validity and reliability, the model should be calibrated with measured ground level concentrations.

The model discussed applies only to a continuous, steady point source of emission.

Discrete discontinuous emissions or puffs, larger areas that act as sources, like parking lots, and line sources, like highways, are modeled using variants of the Gaussian approach, but the actual representation used in each case is quite different.

Computer Models for Assessing Atmospheric Dispersion

A number of computer models that run on a desktop PC exist for assessing atmospheric dispersion of pollutants.

These are essentially codifications of the Gaussian dispersion equations that solve the equations many times and output an isopleth plot.

Some models are:

DEPOSlTION 2.0 (U.S. Nuclear Regulatory Commission NUREG/GR-0006, 1993)
CAP88-PC (US. Department of Energy, ER 8.2, GTN, 1992)
RISKIND (Yuan et al. 1993)
HAZCON (Sandia National Laboratories 1991)
TRANSAT (Sandia National Laboratories 1991)
HOTSPOT (Lawrence Livermore National Laboratory, 1996)
MACCS 2 (Sandia National Laboratories, 1993)

CLEANSING THE ATMOSPHERE

Processes by which the atmosphere cleans itself do exist, and include the effect of gravity, contact with the earth's surface, and removal by precipitation.

Gravity

Particles in the air, if they are larger than about a millimeter in diameter, are observed to settle out under the influence of gravity; the carbon particles from elevated diesel truck exhaust are a very good example of such settling.

However, most particles of air pollutants are small enough that their settling velocity is a function of atmospheric turbulence, viscosity, and friction, as well as of gravitational acceleration, and settling can be exceedingly slow.

Particles smaller than 20 μ,m in diameter will seldom settle out by gravity alone.

Gases are removed by gravitational settling only if they are adsorbed onto particles or if they condense into particulate matter.

Sulfur trioxide, for example, condenses with water and other airborne particulates to form sulfate particles.

Particles small enough to stay in the air for appreciable periods of time are dispersed in the air, but in a slightly different way than gaseous pollutants are dispersed.

The dispersion equation must be modified by considering the settling velocity of these small particles.

For particles between 1 and 100 μm in diameter, the settling velocity follows Stokes' law

$$V_t = gd^2 \frac{\rho}{18\mu}$$

where
V_t = settling or terminal velocity,
g = acceleration due to gravity,
d = particle diameter,
ρ = particle density, and
μ = viscosity of air.

The settling velocity modifies the Gaussian dispersion equation, to give the analogous equation

$$C(x, y, 0) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \exp\left(-\frac{(H - (V_t x/u))^2}{2\sigma_z^2}\right)$$

for dispersion of small particles, The factor of in the 0.5 in the first term arises because falling particles are not reflected at the ground surface.

The rate, ω, at which particulate matter is being deposited on the ground, is related to the ambient concentration as shown in

$$\omega = V_t C(x, y, 0) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \exp\left(-\frac{(H - (V_t x/u))^2}{2\sigma_z^2}\right)$$

where ω = the deposition rate (in g/s-m^2).

EXAMPLE 5
Using the data of Example 3, and assuming that the emission consists of particles 10 μm in diameter and having a density of 1 g/cm^3, calculate (1) the ambient ground level concentration at 200 m downwind along the plume centerline, and (2) the deposition rate at that point. The viscosity of the air is 0.0185 g/m-s at 25°C.

The settling velocity is

$$V_t = (9.8 \, \text{m/s}^2)(10^{-5} \, \text{m})^2 \frac{(1 \, \text{g/cm}^3)}{(10^{-6} \, \text{m}^3/\text{cm}^3)(18)(0.0185 \, \text{g/m-s})} = 0.0029 \, \text{m/s},$$

From example 3

$$Q = 18 \, \text{g/s}$$

$$C(0.2, 0, 0) = \frac{18 \, \text{g/s}}{2\pi (5 \, \text{m/s})(35 \, \text{m})(19 \, \text{m})}$$

$$\times \exp\left\{-\frac{1}{2}\left[\frac{60 \, \text{m} - \left(\dfrac{(.0029 \, \text{m/s})(200 \, \text{m})}{5 \, \text{m/s}}\right)}{19 \, \text{m}}\right]^2\right\}$$

$$= 6.03 \times 10^{-6} \, \text{g/m}^3$$

The deposition rate is then

$$\omega = (0.0029 \, \text{m/s})(6.03 \times 10^{-6} \, \text{g/m}^3\text{-s})$$

$$= 1.75 \times 10^{-8} \, \text{g/m}^2\text{-s}$$

Surface Sink Absorption

Many atmospheric gases are absorbed by the features of the earth's surface, including stone, soil, vegetation, bodies of water, and other materials.

Soluble gases like SO_2 dissolve readily in surface waters, and such dissolution can result in measurable acidification.

Precipitation

Precipitation removes contaminants from the air by two methods.

Ruinout is an "incloud" process in which very small pollutant particles become nuclei for the formation of rain droplets that grow and eventually fall as precipitation.

Washout is a "belowcloud" process in which rain falls through the pollutant particles and molecules, which are entrained by the impinging rain droplets or which actually dissolve in the rainwater.

The relative importance of these removal mechanisms was illustrated by a study of SO_2 emissions in Great Britain, where the surface sink accounted for 60% of the SO_2, 15% was removed by precipitation, and 25% blew away from Great Britain, heading northwest toward Norway and Sweden.

CONCLUSION

Polluted air results from both emissions into the air and meteorological conditions that control the dispersion of those emissions.

Pollutants are moved predominantly by wind, so that very light wind results in poor dispersion. Other conditions conducive to poor dispersion are:

- Little lateral wind movement across the prevailing wind direction,

- Stable meteorological conditions, resulting in limited vertical air movement,

- Large differences between day and night air temperatures, and the trapping of cold air in valleys, resulting in stable conditions,

- Fog, which promotes the formation of secondary pollutants and hinders the sun from warming the ground and breaking inversions, and

- High-pressure areas resulting in downward vertical air movement and absence of rain for washing the atmosphere.

Air pollution episodes can now be predicted, to some extent, on the basis of meteorological data. The EPA and many state and local air pollution control agencies are implementing early warning systems, and acting to curtail emissions and provide emergency services in the event of a predicted episode.