Chapter 5 Air Pollution and Control

5.1 Introduction

In addition to global warming and stratospheric ozone depletion, air pollutants also pose local and regional hazards.

Air pollution is the presence in the outdoor atmosphere of one or more air contaminants (i.e., dust, fumes, gas, mist, odor, smoke, or vapor) in sufficient quantities, of such characteristics, and of such duration as to be or to threaten to be injurious to human, plant, or animal life or to property, or which reasonably interferes with the comfortable enjoyment of life or property.

Human activities are the main causes of air pollution problems that threaten to make portions of the earth's atmosphere an inhospitable environment.

In some cases we do not control emissions adequately. We must then rely on dispersion and subsequent natural atmospheric cleansing processes to avoid exceeding pollutant concentrations, which would result in undesirable effects.

Throughout the world, emphasis has been given on controlling the ambient atmospheric concentrations of pollutants to levels at which no health effects will be observed. Control of air pollution is not always easy, for it is impractical to eliminate all emissions of a specific pollutant. On the other hand, it is reasonable to expect control of emissions to the lowest possible level consistent with available technology and within reasonable cost. In practice, emission limits or standards are frequently established rather than ambient air quality standards, because they are far easier for control agency to enforce, although it is the latter that are really desired.

Composition and Structure of the Atmosphere

The total mass of each gas in the atmosphere is given in table 5-1. Varying amounts of most of these gases may be found in each of the four major layers of the atmosphere—the troposphere, the stratosphere, the mesosphere, and the thermosphere (see Fig. 5-1).

The layer of greatest interest in pollution control is the troposphere, since this is the layer in which most living things exist. One of the most recent changes in the atmosphere involves the phenomenon of acid rain. The amount of carbon dioxide is reported to be increasing at a rate of 1.8 mg/m3 per year, a process that may not be reversible. Furthermore, this increase has been accompanied by an equivalent decrease in the atmospheric oxygen (O_2).

5.2 Physical and chemical Fundamentals

Ideal Gas Law:

$$PV = nRT \qquad (5\text{-}1)$$

where P = absolute pressure, kPa

V = the volume occupied by n moles of gas

R = universal gas constant = 8.3143 J/K.mole

T = absolute temperature, K

Table 5-1. Concentration of atmospheric gases in clean dry air at ground level

Gas	Concentration, ppm by volume	Concentration, % by volume
Nitrogen	280,000	78.09
Oxygen	209,000	20.95
Argon	9,300	0.93
Carbon dioxide	320	0.032
Neon	18	0.0018
Helium	5.2	0.00052
Methane	1.5	0.00015
Krypton	1.0	0.0001
Hydrogen	0.5	0.00005
Dinitrogen Oxide	0.2	0.00002
Carbon monoxide	0.1	0.00001
Ozone	0.08	0.000008
Ammonia	0.006	0.000006
Nitrogen dioxide	0.001	0.000001
Sulfur dioxide	0.0002	0.0000006
Hydrogen sulfide	0.0002	0.0000002

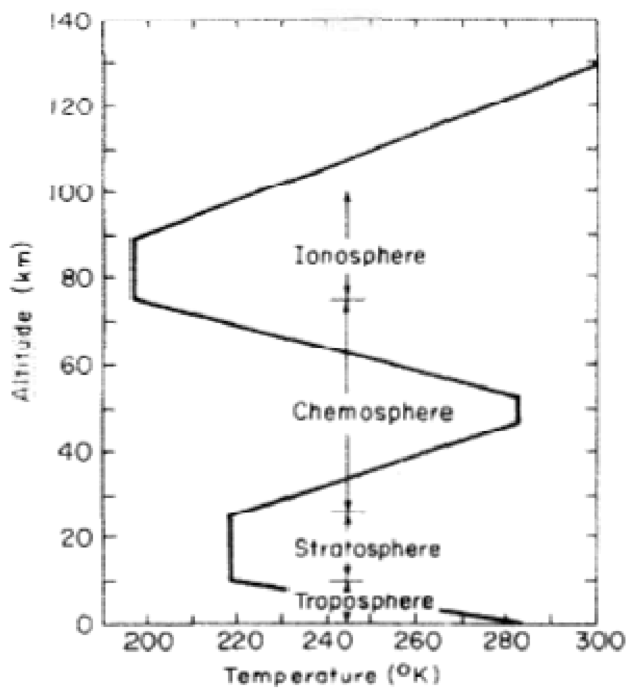

Figure 5-1 Profile of the atmosphere

Dalton's Law of Partial Pressure

The total pressure exerted by a mixture of gases is equal to the sum of the pressures that each type of gas would exert if it alone occupied the container.

$$P_t = P_1 + P_2 + P_3 + \ldots \qquad (5\text{-}2)$$

where P_t = total pressure of mixture

P_1, P_2, P_3 = pressure of each gas if it were in container alone, that is partial pressure.

Adiabatic Expansion and Compression

An adiabatic process is one that takes place with no addition or removal of heat and with sufficient slowness, so that the gas can be considered to be in equilibrium at all times.

With the first principle of thermodynamics we have:

(Heat added to gas) = (increase in thermal energy) + external work done by or on the gas)

Since the left side of the equation is zero (because it is an adiabatic process), the increase in thermal energy is equal to the work done. The increase in thermal energy is reflected by an increase in the temperature of the gas. If the gas is expanded adiabatically, its temperature will decrease.

Units of Measure

The three basic units of measure used in reporting air pollution data are *micrograms per cubic meter* ($\mu g/m^3$), *parts per million* (ppm), and the *micron* (μ) or, preferably, its equivalent, the *micrometer* (μm). Micrograms per cubic meter and parts per million are measures of concentration. Both $\mu g/m^3$ and ppm are used to indicate the concentration of gaseous pollutant. However, the concentration of particulate matter may be reported only as $\mu g/m^3$. The μm is used to report particle size.

Converting μg/m³ ppm. We can use the following formula to convert ppm to $\mu g/m^3$.

$$\mu g/m^3 = \frac{ppm \times g\, mol\, mass \times 10^3}{L/mol}$$

This conversion is based on the fact that at standard conditions (0oC and 101.325 kPa), one mole of an ideal gas occupies 22.414 L. Thus, we can convert the mass of the pollutant Mp in grams to its equivalent volume V_p in liters at standard temperature and pressure (STP):

$$V_p = \frac{M_p}{GMW} \times 22.414\ L/GM \qquad (5\text{—}3)$$

where GMW is the gram molecular weight of the pollutant. For readings made at temperatures (T_2) and pressures (P_2) other than standard conditions, the standard volume, 22.414 L/GM, must be corrected using the ideal gas law. The following can be used the formula:

$$22.414 \frac{L}{GM} \times \frac{T_2}{273\ K} \times \frac{101.325\ kPa}{P_2} \qquad (5-4)$$

Since ppm is a volume ratio, we may write

$$ppm = \frac{V_p}{V_a} \qquad (5-5)$$

where V_a is the volume of air in cubic meters at the temperature and pressure of the reading.

Example 5-1. A one-cubic-meter sample of air was found to contain 80 μg/m^3 of SO_2. The temperature and pressure were 25°C and 103.193 kPa when the air sample was taken. What was the SO_2 concentration in ppm?

5-3 Sources and Classification of Pollutants

To have an air pollution incident, or to have a problem, there are three factors that must occur simultaneously. There must be sources, a means of transport, and receptors. Figure 5-2 illustrates the process. Air pollution sources are relatively common knowledge. Their strength, type, and location are important factors. By transport, reference is made to the meteorological conditions, and the topography and climatology of a region, which are the important factors in dispersion — that is, in getting the material from the sources to the receptors. The receptors include human beings, other animals, materials, and plants. We also know that air pollution can affect visibility and can endanger our lives simply by making it difficult to travel on the highways and difficult for planes to land.

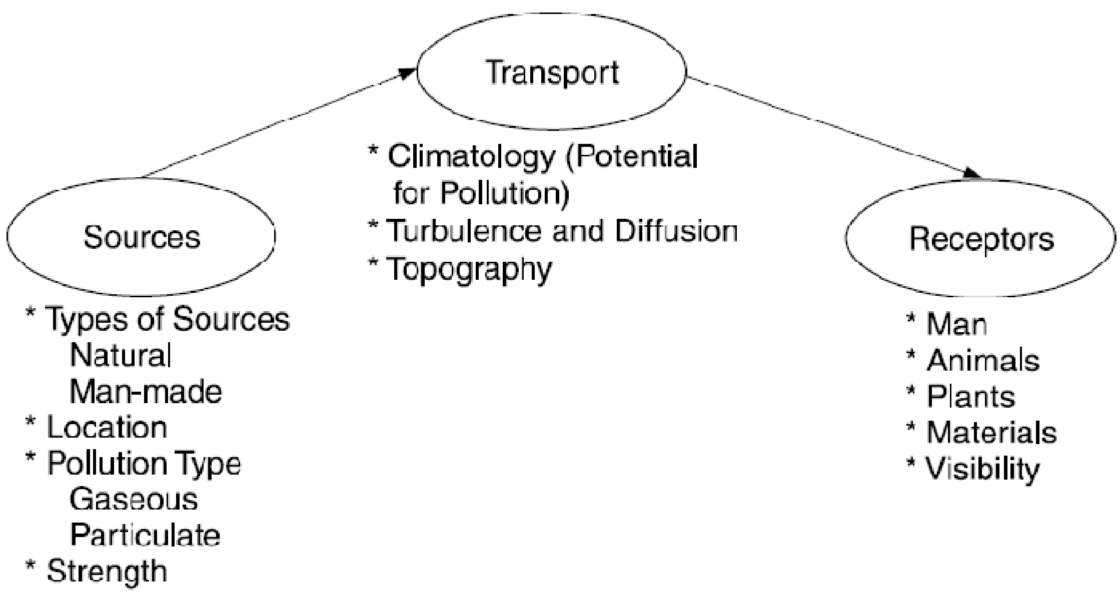

Figure 5-2. The trilogy: Sources — Transport — Receptors.

Air pollutant sources can be categorized according to the type of source, their number and spatial distribution, and the type of emissions. Categorization by type includes natural and manmade sources. Natural air pollutant sources include plant pollens, wind-blown dust, volcanic eruptions, and lightning-generated forest fires. Manmade sources include transportation vehicles, industrial processes, power plants, municipal incinerators, and others.

Source categorization according to number and spatial distribution includes single or point sources (stationary), area or multiple sources (stationary or mobile), and line sources (see Fig 5-3).

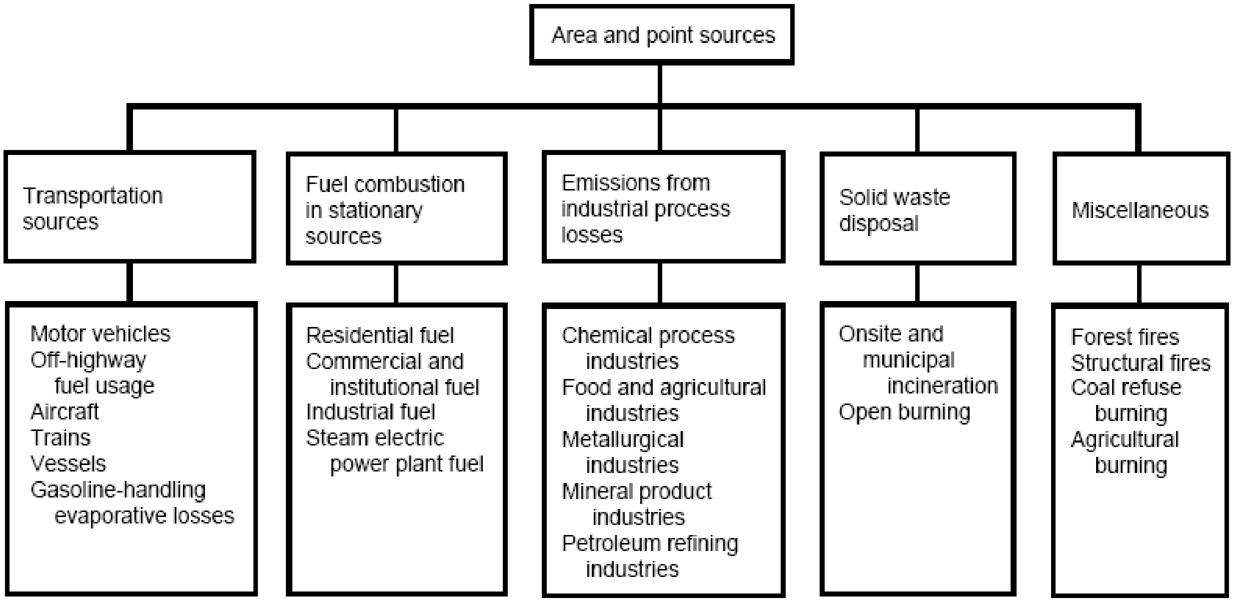

Figure 5-3. Source categories for emission inventories.

Classification of Pollutants

Air pollutants can be classified according to origin, chemical composition, and state of matter.

Origin. According to their origin, pollutants are considered as either primary or secondary air pollutants. *Primary air pollutants* are pollutants in the atmosphere that exist in the same form as in source emissions. Examples of primary air pollutants include carbon monoxide, sulfur dioxide, and total suspended particulates. *Secondary air pollutants* are pollutants formed in the atmosphere as a result of reactions such as hydrolysis, oxidation, and photochemical oxidation. Secondary air pollutants include acidic mists and photochemical oxidants. In terms of air quality management, the main strategies are directed toward source control of primary air pollutants. The most effective means of controlling secondary air pollutants is to achieve source control of the primary air pollutant; primary pollutants react in the atmosphere to form secondary pollutants.

Chemical Composition. Air pollutants can further be classified according to their chemical composition, as either organic or inorganic. *Organic compounds* contain carbon and hydrogen, and many also contain elements such as oxygen, nitrogen, phosphorus, and sulfur. Hydrocarbons are organic compounds containing only carbon and hydrogen. *Inorganic materials* found in contaminated atmosphere include carbon monoxide (CO), carbon dioxide (CO2), carbonates, sulfur oxides, nitrogen oxides, ozone, hydrogen fluoride, and hydrogen chloride.

State of Matter. As seen in Table 5-2, air pollution sources can also be categorized according to whether the emissions are *gaseous* or *particulates*. Particulate pollutants, finely divided solids and liquids, include smoke and dust emissions from a variety of sources. Examples of gaseous pollutant emissions include carbon monoxide, hydrocarbons, sulfur dioxide, and nitrogen oxides. Often, an air pollution source emits both gases and particulates into the ambient air.

Table 5-2 Classification of pollutants

Major classes	Subclasses	Typical members of subclasses
Particulates	Solid	Dust, smoke, fumes, fly ash
	Liquid	Mist, spray
Gases		
Organic	Hydrocarbons	Hexane, benzene, ethylene, methane, butane, butadiene
	Aldehydes and ketones	Formaldehyde, acetone
	Other organics	Chlorinated hydrocarbons, alcohols
Inorganic	Oxides of carbon	Carbon monoxide, carbon dioxide
	Oxides of sulfur	Sulfur dioxide, sulfur trioxide
	Oxides of nitrogen	Nitrogen dioxide, nitric oxide
	Other inorganics	Hydrogen sulfide, hydrogen fluoride, ammonia

Criteria Air Pollutants

Two kinds of ambient pollutants are regulated under the Clean Air Act: Criteria pollutants and hazardous air pollutants. The Clean Air Act characterizes five primary pollutants and one secondary pollutant as criteria air pollutants. These six pollutants are emitted in relatively large quantities by various sources and tend to threaten human health or welfare.

The five primary criteria pollutants include the gases *sulfur dioxide* (SO_2), *nitrogen oxides* (NO_x), and *carbon monoxide* (CO) and solid or liquid *particulates* (smaller than 10 µm, PM-10) and *particulate lead*. *Ozone* (O_3) is the secondary criteria pollutant regulated under Clean Air Act.

Carbon Monoxide

Nitrogen Dioxide

Sulfur Oxides

Effects of Particulates

Effects on human health – respiratory illness (depends upon the concentration)

Lead particulates – blood forming systems, the nervous system, and the renal system.

Effects on plants and animals – damage and inhibit growth to plant tissue

interfere with photosynthesis

Effects on materials – soiling clothing, corroding metals (RH > 75%), eroding building surfaces, and discoloring and destroying painted surfaces.

Effects of Sulfur Oxides

Effects on human health – irritate the mucous membrane → bronchitis and pulmonary emphysema

Effects on plants – damaging tissues, or bleaching

Effects on materials – sulfuric acid aerosols attack building materials → marble, limestone, roofing slate, and mortar.

Effects of Nitrogen Oxides

Effects on human health – irritates the aveoli of the lung

high burning of eye

destroy the lining of the lung

lead to cancer

Effects of Carbon Monoxide

At high concentration (>2% COHb level) affects human aerobic metabolism

Affinity to Hb 200 times higher that O_2