7.1.4 AIR QUALITY

Ambient or ground-level tropospheric processes are of paramount importance because the resultant air quality relates primarily to human health, but also affects visibility, vegetation, crops, animals, and buildings. Pollutant concentrations are dependent on emissions and on meteorological conditions, which affect their movement and dynamics. For example, local thermal stability and wind conditions affect the dispersal of stack emissions, and regional wind patterns determines the distribution of pollutants over large distances.

Major pollutants of air include carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2). Most of these are relevant to our study of coal-fired power plants. Some pollutants are emitted directly, whereas others are formed by precursors originating from reactions involving directly emitted pollutants. For example, PM and SO_2 are emitted directly, but O_3 is formed by precursors. In some cases, further precision in defining the pollutant is required according to its effect. For example, PM is divided into major types according to particle size; PM_{10} is for particles smaller than 10 μm and $PM_{2.5}$ is for particles smaller than 2.5 μm. Their effect on human health is different.

Atmospheric chemistry influences concentrations of all these compounds. For example, NO_2 has high concentration near the ground in the troposphere and at the stratosphere. Its main source is nitrous oxide (N_2O), which arises from biological processes. Nitrogen dioxide is the main natural sink of stratospheric ozone [5]. In the stratosphere, N_2O photodissociates into O and N_2, nitrous oxide reacts with O to form nitric oxide (NO), and then NO reacts with ozone to produce NO_2.

In the United States, the Clean Air Act [6,7] is the major legislation on air quality and requires the U.S. Environmental Protection Agency to set National Emissions Standards and National Ambient Air Quality Standards (NAAQS) [8]. The standards apply to six criteria pollutants: CO, Pb, NO_2, O_3, PM_{10}, $PM_{2.5}$, and SO_2. For example, NAAQS ozone is subject to both primary and secondary standards, by 8-hour averaged values, the annual fourth highest daily maximum 8-hour concentration, averaged over 3 years should not exceed 0.075 ppm. For $PM_{2.5}$, the annual standard is that the annual mean, averaged over 3 years, should not exceed 12 $\mu g.m^{-3}$ as the primary standard and 15 $\mu g.m^{-3}$ as the secondary standard. The 24-hour standard is that the 3-year average of the 98th percentile of a 24-hour average should not exceed 35.5 $\mu g\ m^{-3}$.

7.1.5 ADVECTION

Transport of constituents as well as of energy (in the form of heat and enthalpy) in a fluid is characterized by several processes. *Advection* consists of transporting the constituents along with the bulk of the fluid moving with velocity v, which can be a vector (i.e., includes horizontal and vertical components). This occurs, for example, by wind or a current in the fluid with that velocity field. A simple example in liquids is transport within a pipe or a river. Advection typically describes horizontal transport in the atmosphere.

Given the concentration of a constituent X in mg/l (ppm) or mg/m^3 (ppb), and volume flow rate vA, where v is velocity (m/s) and A is the cross-section area (m^3/~~s~~), the flux density due to advection is $F = vX$ and given in $mg/(m^2s)$.

Example 7.2

Suppose air flows at a steady 3 m/s horizontally with 200 ppb concentration of SO_2. What is the SO_2 flux density? Answer: $F = vX = 3\,\dfrac{m}{s} \times 200 \times \dfrac{mg}{m^3} = 600\,\dfrac{mg}{m^2s}$.

The same concept applies to energy, where instead of concentration we use heat or enthalpy in the fluid. Given the energy, say, heat q per unit mass in kJ/kg, the density ρ of the fluid in kg/m^3, and the volume flow rate vA, where v is velocity (m/s) and A is the cross-section area (m^3/s), we can calculate energy flux as $F = \rho q v$ in $kJ/(m^2s)$.
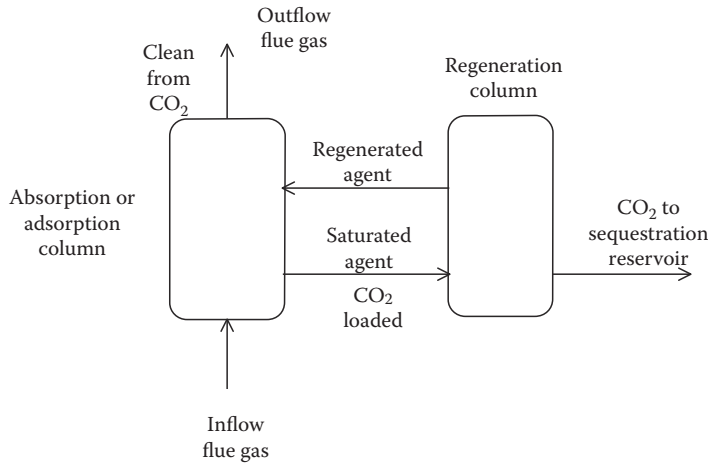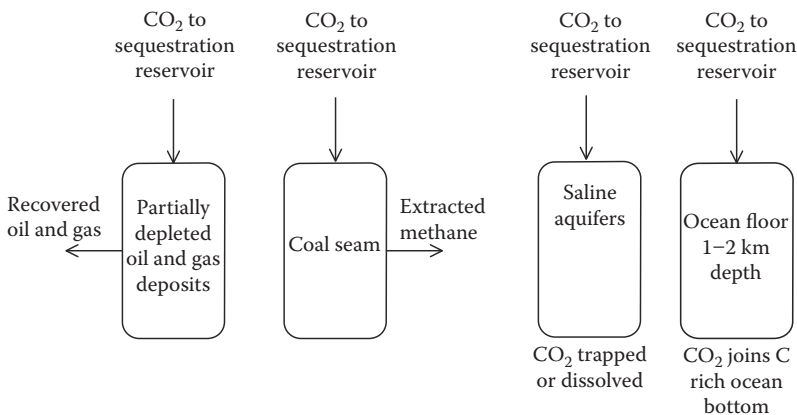
FIGURE 7.6 Direct carbon sequestration: separation from flue gas.

CO_2 (Figure 7.6). In absorption, the CO_2 in the flue gas is assimilated into the mass of the absorbing agent. In adsorption, the CO_2 adheres to the surface of the adsorption agent. Pilot facilities use monoethanolamine (MAE) as an absorbing agent. The regeneration process requires energy and therefore reduces the overall efficiency of power production. This technology is mature at small scales, but new approaches are needed for larger scales; research is looking at membranes to substitute absorption–regeneration, algae grown under controlled conditions, and nature-inspired absorbers such as carbonic anhydrase.

MEA

7.6.2 POTENTIAL RESERVOIRS, OIL, GAS, AND COAL SEAMS

Potential reservoirs are spent oil and gas deposits, coal seams, saline aquifers, and the bottom of the ocean (Figure 7.7). The first two of these processes include a by-product of the injection and represent an opportunity for financing the sequestration. When using partially depleted oil and gas deposits, injecting the CO_2 represents a form of recovery, which helps offset costs of sequestration. However, the recovered oil and gas when burned will emit CO_2 and this amount would have to be lower than CO_2 injected for net positive sequestration.

FIGURE 7.7 Direct carbon sequestration: storage in nonatmospheric reservoirs.