pH and very high BOD (biological oxygen demand). With a low pH, silage liquor can be highly corrosive; it can attack synthetic materials, causing damage to storage equipment and leading to accidental spillage.

Agricultural operations, those that raise animals and grow crops, can generate emissions of gases, particulate matter and chemical compounds (Fig. 13.8). For example, animals confined to a barn or area (rather than field grazing), produce large amounts of manure. Manure emits various gases, particularly ammonia into the air. This ammonia can be emitted from the animal houses, manure storage areas or from the land after the manure is applied. In crop production, the misapplication of fertilizers, herbicides and pesticides can potentially result in aerial drift of these materials.

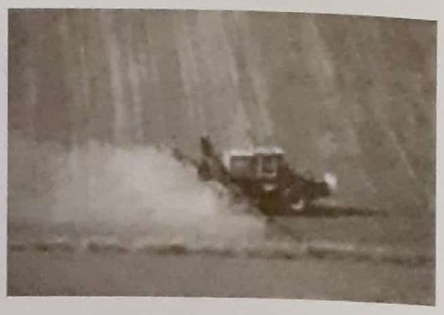

Figure 13.8 *Spraying insecticide, pesticide or fertilizer during agricultural operations.*

(iv) Natural sources

Natural sources of air pollution are sources not caused by people or their activities. An erupting volcano (Fig. 13.9) emits particulate matter and forest fires (Fig. 13.10) can emit large quantities of pollutants, plants and trees emit hydrocarbons and dust storms can create large amounts of particulate matter. Wild animals in their natural habitat are also considered natural sources of pollution given that there is a certain amount of natural pollution, it is very important to control the 'excess' pollution caused by man's activities.

Figure 13.9 *Volcano pollution.*

Figure 13.10 *Forest fire pollution.*

13.3.4 Impacts of Air Pollution

Pollutions are due to atmospheric deposition of nitrogen (NO_x) and other chemical contaminants. These pollutants dramatically impact the watershed as shown in Fig. 13.1.

The effects of nitrogen can be seen in the following:

(i) *Acid rain*: Nitrogen oxide (NO_x) is one of the key air pollutants which causes acid deposition, and results in adverse effects on aquatic and terrestrial ecosystems (Fig. 13.11). Acid deposition increases the acidity of water and soils. Increases in water acidity can impair the ability of certain fish and aquatic life to grow, reproduce and survive. Increases in soil acidity can impair the ability of some types of trees to grow and resist disease.

(ii) *Smog*: It is a collection of pollutants. It is formed by NO_x, particulate matter and humidity, all mixed together. Smog reduces how far and how clearly we can see through the air, an effect called visibility reduction or regional haze. General atmospheric conditions are that haze and ozone occur at the same time and the mix of the two is called smog (Fig. 13.12).

Figure 13.11 *Formation of acid rain cloud due to the presence of CO_2, SO_2, NO_x, etc. with moisture.*

(iii) *Eutrophication*: Reduced levels of dissolved oxygen in water due to increased mineral and organic nutrient deposits produce algae and other water plants that choke other forms of life in the oxygen competition. Soil erosion, phosphorous and direct runoff from feedlot operations and intensive agriculture are the main cause.
When excess nitrogen causes accelerated growth of algae, the algae blocks sunlight, needed for submerged aquatic vegetation to grow, when the algae dies it sinks to the bottom and decomposes in a process which depletes the water of oxygen.

Figure 13.12 *Smog formation in the atmosphere.*

(iv) *Accumulation*: Nitrogen compounds percolate through soil and reach drinking water sources, and these nitrate contaminants pollute the water.
The effects of chemical contaminants can be seen in the following:

(v) *Bioaccumulation*: Chemical contaminants increase with concentration as it moves through the food chain. Example: an invertebrate eats contaminated algae, a small fish eats many contaminate invertebrates, a large fish eats many small fish, and humans eat the big fish which is now loaded with the chemical. Chemical contaminant can accumulate and bind to the sediments they deposit on. When this happens, the chemical contaminants are moved wherever the sediments are moved. Chemical contaminants can change a plant species composition, and make species more susceptible to disease, weather and insect damage. Changes such as these challenge a species ability to reproduce and develop.

(vi) *Persistent*: Chemical contaminants do not break down or diminish over time.

13.3.5 Classification of Air Pollutants

Air pollutants are classified into two types according to their origin.

(i) *Primary pollutants* which are directly injected into air, e.g. SO_2, CO, oxides of nitrogen, dust particles, etc.

(ii) *Secondary pollutants* which are not directly introduced into air but are found in the atmosphere by chemical or photochemical reactions among the constituent of air, e.g. ozone, PAN, etc.

Another method of classification of air pollutants is based on their physical state.

(i) *Gases*, e.g. CO, NO, hydrocarbon vapours, SO_2, etc.

(ii) *Aerosol particulates* which involve solids such as smoke and dust and liquids like fog, sprays, etc.

A third type of classification is based on the chemical composition of the pollutant.

(i) *Inorganic pollutants:* Oxides of N_2, CO, SO_2, H_2S, etc.

(ii) *Organic pollutants:* Hydrocarbons, aldehydes, ketones, etc.

13.3.6 Sources, Ill Effects and Remedies of Air Pollutants

There are six primary pollutants of air. They are (a) SO_2, (b) CO, (c) oxides of nitrogen, (d) volatile organic vapours, (e) particulate matter and (f) ozone.

Their natural and anthropogenic (manmade) sources, ill effects and remedial measures are given below.

13.3.6.1 Sulphur Dioxide

(a) *Natural source*: Volcanic eruptions produce gases containing SO_2. When plants decay they produce H_2S, which gets oxidised in air by ozone to form SO_2.

$$H_2S + O_3 \rightarrow H_2O + SO_4^{2-}$$

(b) *Anthropogenic sources:* Combustion of sulphur containing fossil fuels is the main manmade source. Roasting of sulphide ores of metals also produce SO_2.

$$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2$$

The concentration of SO_2 in air always remained below the permissible level. The concentration of SO_2 is high only in low altitude regions due to anthropogenic forces.

(c) *Ill effects of SO_2*:

(i) *On human beings:* Concentration of SO_2 to about 20 ppm may cause eye irritation and affect digestive systems. Concentration above 400 ppm may be fatal.

(ii) *On plants:* Plants are damaged even at 1 ppm and for some plants yellowing of leaves takes place due to the presence of sulphur dioxide content in air.

(iii) *On materials:* Yellowing of paper, loss of strength due to corrosion of metals and loss of strength of buildings may be caused by SO_2. Acid rain is also caused by SO_2.

(d) *Control of SO_2 pollution*: The main source of SO_2 is the burning of coal. Control of SO_2 pollution may be done by passing the emitted gases through a slurry of limestone when SO_2 is absorbed. Air is blown through the slurry to convert calcium sulphite to calcium sulphate.

$$CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$$

$$CaSO_3 + \tfrac{1}{2} O_2 \rightarrow CaSO_4$$

In fluidized bed combustion finely powdered coal and limestone is fed into the chamber and fluidized by blowing air at about 1000°C. All the above changes take place in the chamber.

13.3.6.2 Carbon Monoxide

(a) *Natural source* by the oxidation of methane from marshy places by O_2.

$$CH_4 + \frac{1}{2} O_2 \rightarrow CO + 2H_2O$$

(b) *Anthropogenic source:*

(i) Incomplete combustion of carbon and carbon-containing fuels. CO is one of the major pollutants present in automobile exhaust gases.

(ii) Reaction of CO_2 with carbon at high temperature.

$$CO_2 + C \rightarrow 2CO$$

(c) *Ill effects on human beings:* 10 ppm is the admissible level of CO in air. Concentration above 110 ppm affects the respiratory system. At higher concentration it leads to headache, fatigue, unconsciousness and finally to death. This is caused because CO forms a stable complex carboxyhaemoglobin with haemoglobin of the blood. Haemoglobin loses its capacity to carry oxygen to the cells.

(d) *Control of CO Pollution:* The main source of CO pollution is automobile exhaust. These emissions are controlled by using a catalytic converter where CO is oxidised to CO_2.

$$CO + \frac{1}{2}O_2 \rightarrow CO_2$$

13.3.6.3 Organic Vapours

(a) *Natural source:* From marsh gas and from gases from petroleum wells.

(b) *Anthropogenic source:* The major source is from the unburnt gases of automobile exhaust from various industrial processes, perfumes we use in day-to-day life.

(c) *Ill effects:* On their own hydrocarbons do not produce any pollution. They are however converted to photochemical oxidants called PAN (peroxyacyl nitrate) by a series of reactions. PAN is the cause of photochemical smog.

(d) *Control of hydrocarbon pollution*: The main source of anthropogenic hydrocarbon pollution is exhaust gases of automobiles. Control can be done by having a catalytic converter which helps in the oxidation of hydrocarbons to CO_2 and water.

$$C_x\frac{H}{y} + \left(x + \frac{y}{4}\right)O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

13.3.6.4 Oxides of Nitrogen

The three oxides of nitrogen found in the atmosphere are (N_2O) nitrous oxide, (NO) nitric oxide and (NO_2) nitrogen dioxide.

(a) *Natural source:*

(i) By biological oxidation of nitrogenous compounds in the soil N_2O and NO are formed. This easily gets oxidized to NO_2, in air.

(ii) During lightning N_2 and O_2 of air combine to form NO which then gets oxidized to NO_2.

(b) *Anthropogenic source:* Internal combustion engines operate at high temperatures. N_2 and O_2 of the air in the engine form NO and then NO_2. Thus, the exhaust gases from IC engine contain NO and NO_2.

(c) *Ill effects of oxides of nitrogen*

On human beings: Causes eye irritation and respiratory problems, produces acid-induced irritation and lung cancer.

On plants: Nil

On materials: (i) Causes acid rain which damages old monuments and buildings. (ii) Causes formation of photochemical smog which leads to poor visibility of roads and landing difficulties to aircrafts.

(d) *Control of the oxides of nitrogen:* In the IC engines catalytic converter is used for the decomposition of the oxides of nitrogen to N_2 and O_2.

$$\underset{\text{(exhaust gas)}}{2NO_2} \xrightarrow{\text{Pt/Rh. catalyst}} N_2 + O_2$$

13.3.6.5 *Particulate Matter*

Particles (both solids and liquids) with a size around 10 μm form particulate pollution in air. They are also called aerosol. Dust and soot are solid sols while fog and mist form liquid aerosol.

(a) *Natural source* by dust storms, forest fire, etc.

(b) *Anthropogenic source:*

(i) Soot is produced during the combustion of coal, wood, fuel oil, house and municipal garbage and tobacco smoking.

(ii) Dust is produced during material handling and crushing, grinding of ores, etc. Dust is also produced during mixing and packaging of powdered substances like chemicals, flours, starches, etc. Construction of houses, roads, dams and mining also cause formation of dust. House cleaning, body sprays, spraying of crops, engine exhaust also produce aerosols. Flyash from thermal power plants and cement industries is another major source.

(c) *Ill effects of particulate pollution:* Smoke causes respiratory problems and may lead to TB. Silica dust causes asbestosis. Lead dust produces lead poisoning and mercury dust produces kidney problems.

13.3.6.5.1 Control of Particulate Matter

Various methods for the control of particulate matter in air are available depending on the size of particles, their physical nature and the economy involved.

(a) Fabric filter

Dust particles from dry gases can be removed using fabric filters. It consists of fibrous materials with fine pores suspended in a chamber (Fig. 13.13). The gas is allowed to pass through the filters when particulate matter is filtered at the bags. When the mechanical shaker is operated the collected dust particles fall down. Blowing air in the opposite direction can also be done to remove dust particles from the bags.

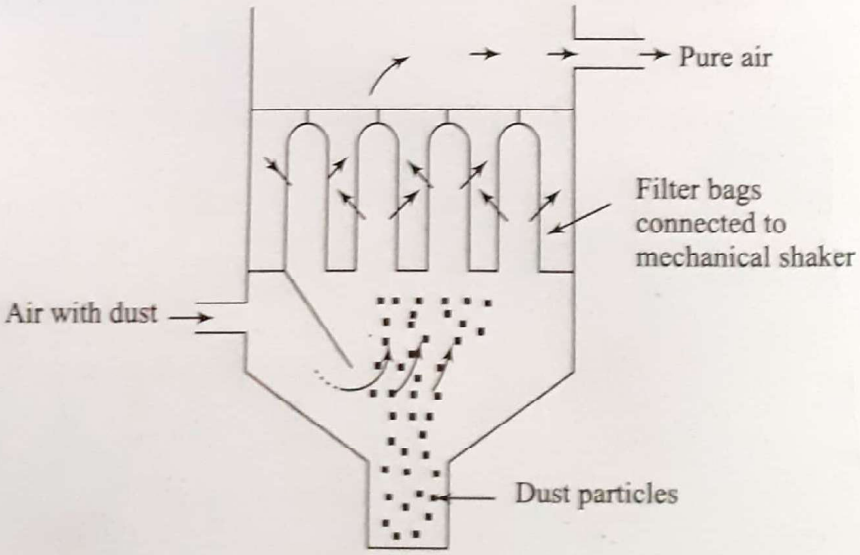

Figure 13.13 *Fabric filter.*

Fabric filters are simple to operate, and have high collection efficiency. But it can be used only for dry gases, requires maintenance and replacement of costly fabrics.

(b) Gravity separation

Air is allowed to flow through dust-settling tanks slowly in one direction. The suspended heavier particles settle down and collect at the conical portions of the tank. Purified air flows out (Fig. 13.14).

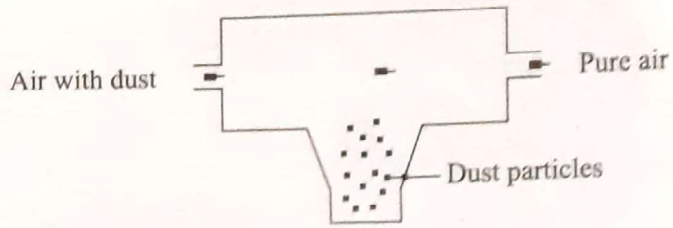

Figure 13.14 *Gravity Separator.*

(c) Cyclone separator (centrifugal separator)

The principle of operation of a cyclone separator is based on centrifugal force to separate dust particles from gas streams. The principle is shown in Fig. 13.15.

A cyclone separator consists of a cylindrical centrifugal chamber, inner tube, conical base and dust collector. The impure air containing dust particles is admitted into the chamber tangent to the surface. It is made to move in a spherical manner down the chamber and pass up in smaller spirals through the inner tube. Under the influence of the centrifugal force dust particles get separated and collect in the conical base. Purified air leaves the chamber through the top of the inner tube.

This method is simple, maintenance free and is economical. But it has low efficiency to smaller particles.

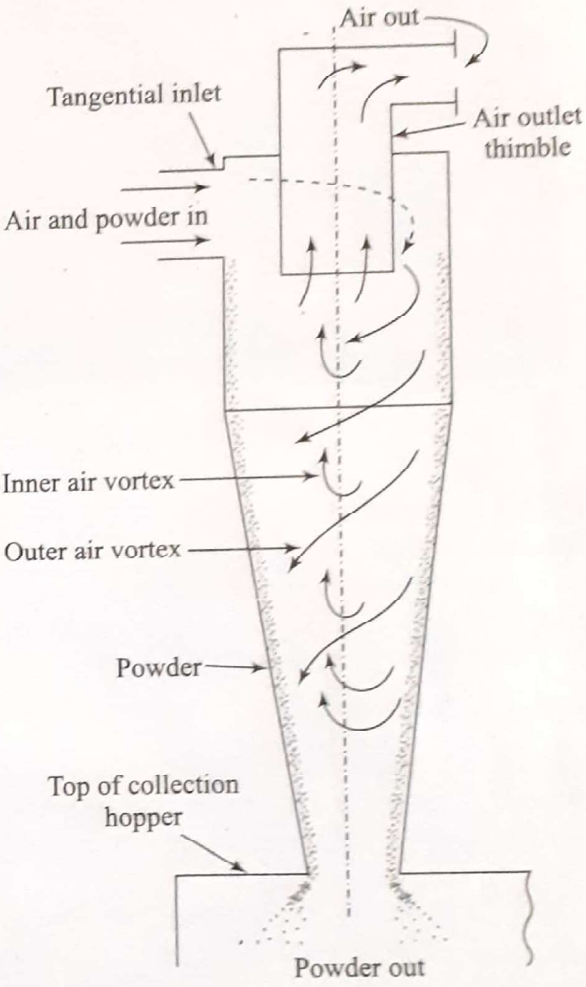

Figure 13.15 *A typical cyclone separator.*

(d) Wet scrubber

Impure air is allowed to ascend a tower and water is sprayed from the top (Fig. 13.16).

Descending water wets the dust particles and settles the particle at the bottom of the chamber as sludge. Scrubber also removes water-soluble gaseous impurities.

This method is also simple and removes both dust particles and water-soluble gases. It is highly efficient. But disposal of sludge becomes costly, large quantities of water is required and air pollution now becomes water pollution.

(e) Electrostatic precipitator

Cottrell electrostatic precipitators are widely used in industries to remove particulate matter from gaseous effluents. They are connected to the exhaust outlets of chimneys Fig. 13.17. The exhaust gas stream of industrial plant is allowed to pass between metal electrodes maintained at a high potential of 50,000 volts.

The pointed electrodes develop high intensity current and produce coronas in which the gas molecules get ionized releasing electrons from the gases. The electrons so generated collide with the suspended particles present in the gas and the particles become negatively charged. These negative particles are attracted by the collection electrode. The discharged

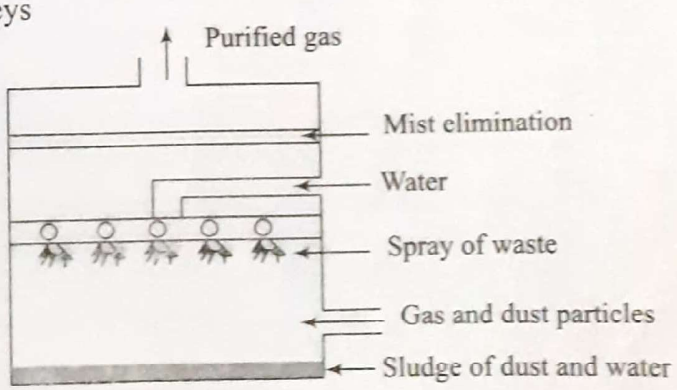

Figure 13.16 *Wet scrubber.*

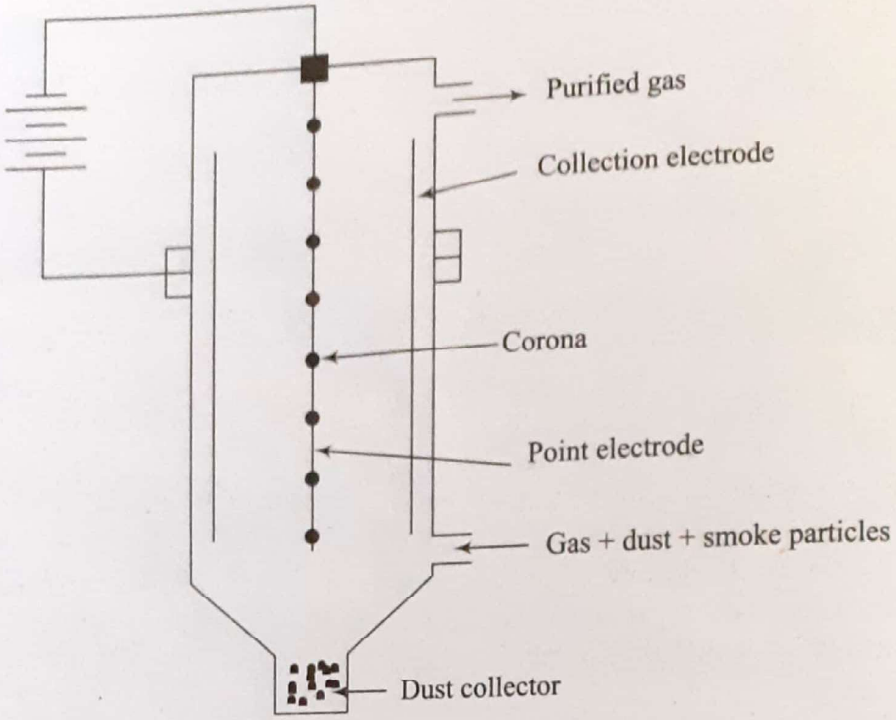

Figure 13.17 *An electrolytic precipitator.*

particles are removed by tapping or vibrations of the electrode. The particles collect in the conical collector. Dust-free gas flows out at the top.

The method has low maintenance cost with high collection efficiency, large quantities of gas can be cleaned. Initial cost is very high. It can be used only for particulate impurities, and gaseous impurities cannot be removed.

13.3.7 Acid Rain

Acid rain is a result of air pollution. When any type of fuel is burnt, a large number of different chemicals are produced. The smoke that comes from a fire or the fumes that come out of a car exhaust do not just contain the sooty grey particles that you can see—they also containa lot of invisible gases that can be even more harmful to our environment.

Power stations, factories and cars all burn fuels and therefore they all produce polluting gases. Some of these gases (especially nitrogen oxides and sulphur dioxide) react with the tiny droplets of water in clouds to form sulphuric and nitric acids. The rain from these clouds then falls as very weak acid—which is why it is known as 'acid rain'.

Rainwater is slightly acidic since it dissolves varying amounts of CO_2 from air. The lowest pH of rainwater is 5.6.

$$H_2O + CO_2 \rightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

In some places in western countries sometimes the pH of rainwater comes down to 4.5 and even up to 2.4. Such a rain is called acid rain (Fig. 13.18). Two main sources of acidity in rain are sulphur dioxide and oxides of nitrogen. When sulphur containing fossil fuels are burnt they produce SO_2 which in presence of rainwater and air forms H_2SO_4.