



## Introduction

The atmosphere, which makes up the largest fraction of the biosphere, is a dynamic system that continuously absorbs a wide range of solids, liquids, and gases from both natural and man-made sources. These substances travel through air, disperse, and react with one another and with other substances both physically and chemically. Most of these constituents, eventually find their way into a depository such as the ocean, or to a receptor such as man. Some substances such as helium, however, escape from the biosphere. Others such as carbon dioxide, may enter the atmosphere faster than they enter a reservoir and thus gradually accumulate in the air.

Clean, dry air contains 78.09% nitrogen by volume and 20.94% oxygen. The remaining 0.97% is composed of a gaseous mixture of carbon dioxide, helium, argon, krypton, nitrous oxide and xenon, as well as very small amounts of some other organic and inorganic gases whose amount in the atmosphere vary with time and place. Various amounts of contaminants continuously enter the atmosphere through both natural and man-made processes that exist upon the earth. That portion of these substances which interacts with the environment to cause toxicity, disease, aesthetic distress, physiological effects or environmental decay, has been labelled by man as a 'pollutant'.

In general, the actions of people are the primary cause of pollution and as the population increases, the attendant pollution problems also increase proportionately. The first significant change in man's effect on nature came with his discovery of fire. Prehistoric man built a fire in his cave for cooking, heating, and to provide light. The problem of air pollution came into existence at this time.

The British Parliament passed an Act in 1273, forbidding the burning of coal in London because it was beginning to choke the atmosphere. In 1300, King Edward I issued a royal proclamation, "Whosoever shall be found guilty of burning coal shall suffer the loss of his head." In 1306, a man was executed for violating this regulation. Later, the law fell into disuse as the industrial revolution took place in England.

Air pollution is basically the presence of foreign substances in air. Some specific definitions of air pollution are given below.

[ "Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke, or vapour, in quantities, with characteristics, and of durations such as to be injurious to human, plant,

or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property."

**6 NO-19** —Engineers Joint Council (U.S.A.)  
"Air pollution is the presence in ambient atmosphere of substances, generally resulting from the activity of man, in sufficient concentration, present for a sufficient time and under circumstances which interfere significantly with the comfort, health or welfare of persons or with the full use or enjoyment of property."

—Indian Standards Institution IS:4167 (1966).  
"Air pollution is the excessive concentration of foreign matter in the air which adversely affects the well being of the individual or causes damage to property."

—American Medical Association

Since air pollution has been mainly caused by rapid industrialisation in some western countries, some critics comment on air pollution as 'the price of industrialisation'. Air pollution caused by automobiles has been described as the 'disease of wealth'.

Air pollution means different things to different people. To the householder it may be an eye irritation and soiled clothing, to the farmer damaged vegetation, to the pilot dangerously reduced visibility and to industries problems of process control and public relations.

Further, the problem of air pollution varies from place to place. For example, air pollution in Tokyo is not the same as that in Bombay.

Today, the natural terrain that surrounds large cities is recognised as having a significant bearing on the problem of air pollution. However, this is not an altogether new concept either. Historians tell us that Los Angeles which in recent years has become a national symbol of comparison for excessive smog levels, was known as the 'valley of smokes' when the Spaniards first arrived there.

It has been found that a significantly increasing volume of particulate matter entering the atmosphere, scatters the incoming sunlight. This reduces the amount of heat that reaches the earth and tends to reduce its temperature. The decreasing mean global temperature of recent years has been attributed to the rising concentration of air-borne particles in the atmosphere. A counter acting phenomenon commonly referred to as the "greenhouse effect" is caused by the increasing amounts of carbon dioxide found in the atmosphere. It has been estimated that if the carbon dioxide content in the atmosphere generated in combustion processes continues to increase at the present rate, the mean global temperature could rise by  $4^{\circ}\text{C}$  in the next five decades. There has been conjecture that this might become a matter of great importance because small temperature increase could cause a partial melting of the ice caps of the earth causing continental flooding and devastating effects on man.

Air pollution can cause death, impair health, reduce visibility, bring about vast economic losses and contribute to the general deterioration of both our cities and country-side. It can also cause intangible losses to historical monuments such as the Taj Mahal which is believed to be badly affected by air pollution.

On account of large scale industrial activities in advanced countries

notably the USA, UK, and other European countries, fall of acid rain has been reported in Scandinavia. This has reduced forest growth in Scandinavia. In Canada, thousands of lakes have been destroyed due to acid rain. Apart from the international issues involved, the basic ecology is affected. Large scale deforestation apart from creating an imbalance in the oxygen proportion of the atmosphere, affects weather and rain patterns as well. Industrial activity, particularly in thermal power stations, cement plants, oil refineries, chemical complexes, metallurgical industries, steel plants and fertiliser complexes, causes major problems of air pollution. The effects of air pollution are felt more by the elderly and chest and respiratory complaints are very common among them. Tragic instances of death have also been reported in air pollution episodes such as the London smog of 1952, and the Bhopal gas tragedy of 1984.

It is, therefore, a matter of great importance that engineers of all disciplines consciously incorporate in their designs sufficient constraints and safeguards to ensure that they do not contribute to atmospheric pollution. In addition, they must apply their ingenuity and problem-solving abilities to eliminate air pollution where it exists and restoring the natural environment.

There are three methods of identifying air pollution:

1. Sensory recognition
2. Physical measurement of pollution
3. Effects on plants, animals, and buildings.

These methods are widely used and they have their merits and demerits. Problem is through some effects on the individual. These are:

- (a) Strong or unusual odours
- (b) Reduction in visibility
- (c) Eye irritation
- (d) Acid taste in the mouth
- (e) Feel of grit under foot

These are highly subjective phenomena and vary from individual to individual.

2. Physical measurement—While sensory perception may provide the first indication of the presence of most of the contaminants in the air, it is often not possible to detect trace quantities of many air-borne toxic substances or the presence of radioactive matter through the senses. Their identification requires physical measurement by standard methods of sampling and analysis.

3. Effects on plants, animals and buildings—Effects of air pollution can be observed on the growth of plants and health of animals. Similarly, its deleterious effect on buildings can also be observed. Thus plants, animals, and buildings act to some extent as indicators of certain atmospheric impurities.

These and other aspects of air pollution are dealt with in detail in the subsequent chapters.

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# 2

## Sources and Classification of Air Pollutants

### 2.1 Introduction

An inventory of air contaminants is a necessary first step towards control of air pollution. Air pollutants can be either natural or may be the result of various activities of man like industrial operations. The industrial contaminants can be either by-products of external combustion like smoke, dust, and sulphur oxides or by-products of internal combustion like the reactions in petrol and diesel engines. Further, the emissions can be either primary pollutants or secondary pollutants. The various sources of pollutants can also be broadly grouped under either stationary sources or mobile sources. All these are explained in detail in the following pages.

### 2.2 Classification of Pollutants

Air pollutants can be classified as follows:

1. Natural contaminants  
e.g., natural fog, pollen grains, bacteria, and products of volcanic eruption.
2. Aerosols (particulates)  
e.g., dust, smoke, mists, fog and fumes.
3. Gases and vapours

The various gases and vapours, which are important air contaminants are given in Table 2.1.

Table 2.1 *Air Contaminants*

No.	Group	Examples
1.	Sulphur compounds	$\text{SO}_2$ , $\text{SO}_3$ , $\text{H}_2\text{S}$ , mercaptans
2.	Nitrogen compounds	$\text{NO}$ , $\text{NO}_2$ , $\text{NH}_3$
3.	Oxygen compounds	$\text{O}_3$ , $\text{CO}$ , $\text{CO}_2$
4.	Halogen compounds	$\text{HF}$ , $\text{HCl}$
5.	Organic compounds	Aldehydes, hydrocarbons
6.	Radioactive compounds	Radioactive gases

In addition to the above, studies by various investigators have indicated, that some of these contaminants undergo chemical reactions when they enter the atmosphere. As a result, the end products formed are more harmful than the original contaminants. For example, it is reported that unsaturated hydrocarbons react with nitrogen dioxide in sunlight to form smog.

### 2.2.1 Natural Contaminants

Among natural contaminants pollen is important because of its peculiar properties irritating to some individuals. Pollen grains are the male gametophytes of gymnosperms and angiosperms and they are discharged into the atmosphere from weeds, grasses and trees. Because of wind pollination, thousands of pollen grains are liberated. While air transported pollen grains range chiefly between 10 and 50  $\mu$  (micron) in size, some have been found to be as small as 5  $\mu$  and as large as 100  $\mu$  in diameter.

From the point of view of pollution, air-borne pollutants are significant because of the allergic responses produced in sensitive individuals. Many people suffer from asthma or hay fever. While most victims have an uncomplicated type of hay fever in which the symptoms disappear at the end of the pollen season, some develop bronchitis, bronchial asthma, and dermatitis. (See Allergic Agents, Sec. 5.5.12.)

### 2.2.2 Aerosols

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Aerosols refer to the dispersion of solid or liquid particles of microscopic size in gaseous media, such as dust, smoke, or mist.

An aerosol can also be defined as a colloidal system in which the dispersion medium is a gas and the dispersed phase is solid or liquid.

The term 'aerosol' is used during the time it is suspended in the air. After it has settled either by virtue of its weight, by agglomeration, or by impact on a solid or liquid surface, the term no longer applies. Thus, particulate matter is an air pollutant only when it is an aerosol. However, it is a nuisance both as an aerosol (visibility reduction) and as settled or deposited matter (soiling of surfaces, corrosions).

Aerosols differ widely in terms of particle size, particle density and their importance as pollutants. Their diameters generally range from 0.01  $\mu$  or less, up to about 100  $\mu$ . The following are the various aerosols.

#### Dust

Dust is made up of solid particles predominantly larger than those found in colloids and capable of temporary suspension in air or other gases. They do not tend to flocculate except under electrostatic forces; they also do not diffuse but settle under the influence of gravity.

Dust is produced by the crushing, grinding, etc., of organic and inorganic materials. Generally they are over 20  $\mu$  in diameter, although some are smaller. Fly ash from chimneys varies from 80–3  $\mu$ ; cement, from 150–10  $\mu$ ; foundry dust, from 200–1  $\mu$ . Most of the dust particles settle to the ground as dust fall, but particles 5  $\mu$  or smaller tend to form stable suspensions.

*Smoke*

Smoke consists of finely divided particles produced by incomplete combustion. It consists predominantly of carbon particles and other combustible materials. Generally the size of the particles is less than  $1\text{ }\mu$ . The size of coal smoke particles range from  $0.2\text{--}0.01\text{ }\mu$  and oil smoke particles from  $1.0\text{--}0.03\text{ }\mu$ .

*Mists*

This term refers to a low concentration dispersion of liquid particles of large size. In meteorology, it means a light dispersion of minute water droplets suspended in the atmosphere. Natural mist particles formed from water vapour in the atmosphere are rather large, ranging from  $500\text{--}40\text{ }\mu$  in size. The particles may coalesce.

*Fog*

Fog refers to visible aerosols in which the dispersed phase is liquid. Formation by condensation is usually implied. In meteorology, it refers to dispersion of water or ice in the atmosphere near the earth's surface reducing visibility to less than  $\frac{1}{2}\text{ km}$ . In natural fog the size of the particles ranges from  $40\text{--}1.0\text{ }\mu$ .

*Fumes*

These are solid particles generated by condensation from the gaseous state, generally after volatilisation from melted substances, and often accompanied by a chemical reaction such as oxidation. Fumes flocculate and sometimes coalesce.

Table 2.2 indicates the major sources of atmospheric dust.

**2.2.3 Gases**

Following are the gases in air pollutants:

*Sulphur Dioxide*

This is one of the principal constituents of air pollutants. The main source of sulphur dioxide is the combustion of fuels, especially coal. Therefore, its concentration in the atmosphere depends upon the sulphur content of the fuel used for heating and power generation. The sulphur content of fuels varies from less than 1% for good quality anthracite to over 4% for bituminous coal. In the USA in recent years, there has been a progressive decrease in the average atmospheric concentrations of sulphur dioxide, of several cities, owing to the increased use of coal with a low sulphur content. Air pollution control measures in St. Louis prohibit the use of high-sulphur coal.

Most crude petroleum products contain less than 1% sulphur; a few

Table 2.2 Sources of Atmospheric Dust

Sources	Examples
1. Combustion	Fuel burning (coal, wood, fuel oil) Incineration (house and municipal garbage) Others (open fires, forest fires, tobacco smoking)
2. Materials handling and processing	Loading and unloading (sand, gravel, coal, ores, lime, cement) Crushing and grinding (ores, stone, cement, rocks, chemicals) Mixing and packaging (chemicals, fertilisers) Food processing (flour, corn starch, grains) Cutting and forming (saw mills, wall board, plastics) Metallurgical (foundries, smelters)
3. Earth-moving operations	Industrial (paper, textiles manufacture) Construction (road, buildings, dams, site clearance) Mining (blasting) Agriculture (soil filling, land preparation)
4. Miscellaneous	Winds House cleaning Mud road cleaning Crop spraying Poultry feeding Engine exhaust



contain up to 5%. Refining processes tend to concentrate sulphur compounds in the heavier fractions. Fuel gases also contain sulphur, but, in small quantities.

About 80% of the sulphur in coal and nearly all that in liquid and gaseous fuels is found in flue gases in the form of sulphur dioxide. The remaining sulphur in coal is present as inorganic sulphur and thus remains in the ash. Generally, the concentration of sulphur dioxide in flue gases ranges from 0.05–0.25%, and occasionally is as high as 0.4%.

Another common source of sulphur dioxide in the atmosphere, is metallurgical operations. Many ores, like zinc, copper and lead, are primarily sulphides. During the smelting of these ores, sulphur dioxide is evolved in stack concentrations of 5–10% ( $\text{SO}_2$ ). But, this can be recovered in the form of sulphuric acid.

Among the miscellaneous operations releasing sulphur dioxide into the atmosphere are sulphuric acid plants and paper manufacturing plants. The quantities are usually low and therefore easily amenable to control measures.

The open burning of refuse and municipal incinerators also contribute some amount of sulphur dioxide to the atmosphere.

#### *Hydrogen Sulphide*

Hydrogen sulphide is a foul smelling gas. The sources of its natural emission include anaerobic biological decay processes on land, in marshes

and in the oceans. Volcanoes and natural water springs emit hydrogen sulphide to some extent.

One of the major sources of hydrogen sulphide is the Kraft pulp industry, which uses a sulphide process for manufacturing paper. The other industrial sources of hydrogen sulphide are petroleum refineries, coke-oven plants, viscose rayon plants, and some chemical operations.

Other sulphur compounds that are of interest in air pollution, principally because of their strong odours, are methyl mercaptan ( $\text{CH}_3\text{SH}$ ), dimethyl sulphide ( $\text{CH}_3\text{SCH}_3$ ), dimethyl disulphide ( $\text{CH}_3\text{SSCH}_3$ ) and their higher molecular homologs. The mercaptans are emitted in mixtures of pollutants from some pulp mills, petroleum refineries, and chemical manufacturing plants.

### *Hydrogen Fluoride*

The major sources of fluorides are the manufacture of phosphate fertilisers, the aluminium industry, brick plants, pottery, and ferro-enamel works. Small amounts are also emitted from other metallurgical operations, such as zinc foundries and open-hearth steel furnaces. Small amounts are also liberated in the burning of coal, which normally contains about 0.01% fluorine.

Hydrogen fluoride is an important air contaminant even in extremely low concentrations of 0.001–0.10 ppm by volume. In these concentration levels, hydrogen fluoride is more important in terms of injury to vegetation and animals than in terms of injury to humans (see Sec. 7.5.2 and 6.2.1). The high degree of toxicity of fluorine compounds renders the control of such emissions imperative for industries manufacturing aluminium and phosphate fertilisers.

### *Chlorine and Hydrogen Chloride*

Chlorine is found in polluted atmospheres as the element itself (chlorine), as hydrogen chloride, as chlorine-containing organic compounds such as perchloroethylene and as inorganic chlorides. The last mentioned compounds are solids and hence found in particulate form; the other materials mentioned are present as gases.

The most common sources of chlorine in the atmosphere are from operations in which it is manufactured or used to produce other chemicals. Also as chlorine is used in water purification plants, in sewage plants and in swimming pools, equipment failure sometimes leads to leakage of chlorine into the atmosphere.

Hydrogen chloride is evolved in numerous industrial chemical processes, but it is so easy to recover, that little reaches the atmosphere.

The main effects of chlorine and its compounds are respiratory irritation from chlorine, corrosion by hydrogen chloride, and damage to vegetation from chlorine and hydrogen chloride.

### *Oxides of Nitrogen*

It is probable that oxides of nitrogen are the second most abundant atmospheric contaminants in many cities, ranking next to sulphur dioxide. Generally, the highest concentration of nitrogen oxides in gaseous emissions occurs in effluents from industries where nitric acid is produced or used in chemical reactions. The next highest concentration is in automobile exhausts. Then come effluents from large power plants, and then to a small extent those from low heat burners and furnaces.

Out of seven oxides of nitrogen ( $N_2O$ ,  $NO$ ,  $NO_2$ ,  $NO_3$ ,  $N_2O_3$ ,  $N_2O_4$ ,  $N_2O_5$ ), only nitric oxide and nitrogen dioxide arise from many human activities and are classified as pollutants. In atmospheric analyses they are usually reported as 'total oxides of nitrogen' or " $NO_x$ ". It is a standard practice in the chemical industry to absorb and recover significant quantities of oxides of nitrogen.

Ammonia and ammonium salts are not important air contaminants. Ammonia is an important raw material in fertiliser and organic chemical industries and in the manufacture of nitric acid by the oxidation process. Its recovery is a matter of fundamental importance in the economical operation of such processes.

### *Carbon Monoxide*

Carbon monoxide, an odourless and colourless gas has its major origin in the incomplete combustion of carbonaceous materials. It is a highly poisonous gas and is generally classified as an asphyxiant.

The chief source of carbon monoxide in the atmosphere is combustion, especially due to automobile exhausts. However, except for motor vehicles and other internal combustion engines, very little carbon monoxide is found in the gaseous emissions from properly adjusted, properly operated installations. Although certain industrial operations, such as electric and blast furnaces, some petroleum refining operations, gas manufacturing plants, and coal mines, are potential contributors of carbon monoxide to the atmosphere, automobile exhausts are by far the most important source.

### *Ozone*

The origin of ozone that is found in the air has not been clarified, but it is likely that combustion and sunlight are involved in its production. (See Chapter 12— Photochemical air pollution). Ozone is poisonous and smelly. It exists in great abundance under natural conditions in the upper atmosphere.

### *Aldehydes*

These are produced by the combustion of gasoline, diesel oil, fuel oil, and natural gas. Incomplete oxidation of motor fuel and lubricating oils leads

to the formation of aldehydes. Lower aldehydes may be present in the atmosphere in concentrations about as high as sulphur dioxide. They may also be formed in the air because of photochemical reactions. Formaldehyde is irritating to the eyes.

### *Organic Vapours*

These contaminants include a large number of chemical compounds, including paraffins, olefins, acetylenes, aromatic hydrocarbons, chlorinated hydrocarbons, etc. They are produced by combustion processes (particularly in automobiles), household incinerators, and petroleum processes. It is also probable that they undergo changes in the atmosphere which contribute to the formation of smog.

### *Radioactive Gases*

A major source of radioactive gases and particulate is the nuclear power reactor and related fuel handling facilities. The other sources are experimental accelerators, testing of nuclear bombs in the atmosphere, agricultural, industrial and medical use of radioactive isotopes. Another source of radioactive particulates and gases that is increasing in importance, is the nuclear fuel reprocessing plant.

Table 2.3 indicates the various sources of air pollution

Table 2.3 *Sources of Air Pollution*

No.	Class	Aerosols	Gases and vapours
1.	Combustion processes (domestic burning, thermal power plants, cars, trucks, aeroplanes, and railways. Also refuse burning)	Dust, fume, smoke	SO <sub>2</sub> , NO <sub>2</sub> , CO, organic vapours, odours
2.	Chemical processes (paper mills, cement, fertilisers, etc.)	Dust, fume, mist	Process-dependent (SO <sub>2</sub> , CO, NH <sub>3</sub> , NO <sub>2</sub> , organic vapours, odours)
3.	Petroleum operations	Dust, mist	SO <sub>2</sub> , H <sub>2</sub> S, NH <sub>3</sub> , CO, hydro-carbons, mercaptans
4.	Metallurgical processes (aluminium refineries, steel plants)	Dust, fume	SO <sub>2</sub> , CO, fluorides, organic vapours
5.	Mineral processing	Dust, fume	Process-dependent (SO <sub>2</sub> , CO, fluorides, organic vapours)
6.	Food and feed operations	Dust, mist	Odourous materials
7.	Agricultural activities (a) Crop spraying (b) Field burning	Dust, mist Smoke, fly ash	Organic phosphates, chlorinated hydro-carbons sulphur oxides, organic vapours
8.	Nuclear energy programmes (a) Fuel fabrication (b) Ore preparation (c) Bomb explosion	Dust	Fluorides Iodine-131 and Argon-41 Radioactive gases (Sr-90, Cs-137, C-14, etc.)

### 2.2.4 Primary and Secondary Air Pollutants

Air pollutants can also be broadly classified into two general groups—primary air pollutants and secondary air pollutants.

→ Primary air pollutants are those emitted directly from identifiable sources.

Examples of primary air pollutants:

1. Finer particles (less than  $100\text{ }\mu$  in diameter)
2. Coarse particles (greater than  $100\text{ }\mu$  in diameter)
3. Sulphur compounds
4. Oxides of nitrogen
5. Carbon monoxide
6. Halogen compounds
7. Organic compounds
8. Radioactive compounds

Finer aerosols include particles of metal, carbon, tar, resin, pollen, bacteria, etc.

→ Secondary air pollutants are those which are produced in the air by the interaction among two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photoactivation.

Examples of secondary air pollutants:

1. Ozone
2. Formaldehyde
3. PAN (peroxy acetyl nitrate)
4. Photochemical smog
5. Formation of acid mists ( $\text{H}_2\text{SO}_4$ ) due to reaction of sulphur dioxide and dissolved oxygen, when water droplets are present in the atmosphere.

### Smog

Smog is a synchronym of two words—smoke and fog. Smog can be of two types—photochemical or coal induced.

Photochemical smog is restricted to highly motorised areas in metropolitan cities, e.g., Los Angeles. It occurs under adverse meteorological conditions when the air movement is restricted. Smog is caused by the interaction of some hydrocarbons and oxidants under the influence of sunlight giving rise to dangerous peroxy acetyl nitrate (PAN). Its main constituents are nitrogen oxides, PAN, hydrocarbons, carbon monoxide and ozone. It reduces visibility, causes eye irritation, damage to vegetation and cracking of rubber.

The fog from burning coal covers urban areas at night or on cold days when the temperature is below  $10^\circ\text{C}$  and when calm meteorological conditions prevail, e.g., London (December 1952). This fog consists of smoke, sulphur compounds and fly ash. Prolonged exposure to smog may result in a high mortality rate especially among the elderly and those who have

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histories of chronic bronchitis, asthma, broncho-pneumonia and other lung or heart diseases.

### 2.2.5 Stationary and Mobile Sources

Emissions (air pollutants) may be classified by source, as stationary or mobile. Another method of classifying emission sources is by:

1. Point sources (large stationary sources)
2. Area sources (small stationary sources and mobile sources with indefinite routes)
3. Line sources (mobile sources with definite routes)

Table 2.4 gives a picture of emission inventory source classification.

**Table 2.4 Emission Inventory Source Classification**

Total Sources				
Stationary sources		Mobile sources		
Point sources	Area sources	Line sources	Area sources	
1. Industrial processing	1. Residential heating	1. Highway vehicles	1. Motor vehicles	
2. Power plants	coal	2. Railroad locomotives	light-duty	
3. Fuel Combustion (industrial) coal oil gas	gas oil	3. Channel vessels	medium-duty	
4. Solid waste disposal Municipal incinerators Open burning	2. Institutional & commercial heating coal oil gas		heavy-duty	
5. Miscellaneous	3. On site incineration 4. Open burning 5. Evaporative losses 6. Miscellaneous		2. Railyard locomotives	
			3. Port vessels	
			4. Aircraft (airports)	
			5. Miscellaneous	

## QUESTIONS

1. Classify air pollutants into different categories, indicating their sources.
2. What are the types and sources of particulate matter causing air pollution? Briefly explain them.
3. Identify the various pollution sources of the following air contaminants
  - (a) Sulphur dioxide
  - (b) Hydrogen sulphide
  - (c) Hydrogen fluoride
  - (d) Carbon monoxide
  - (e) Oxides of nitrogen
  - (f) Hydrocarbons
4. What is meant by 'Smog'? Discuss its cause and effects.

5. List the sources of atmospheric dust.
6. List out the industries that cause major air pollution problems.
7. Distinguish between
  - (a) Primary and secondary air pollutants
  - (b) Stationary and mobile sources of air pollutants
8. Explain the following terms with respect to air pollutants
  - (a) Point sources
  - (b) Area sources
  - (c) Line sources
9. Write short notes on:
  - (a) Aerosols
  - (b) Smog
10. Describe the various air pollution sources in an industrialised city like Bombay.

# 3

## Meteorology and Air Pollution

### 3.1 Meteorological Factors Influencing Air Pollution

The degree to which air pollutants discharged from various sources concentrate in a particular area depends largely on meteorological conditions. The application of dispersion theory and a knowledge of local weather conditions are necessary to determine the required stack height for an emission, and to evaluate the intensity of air pollution. Even though the total discharge of contaminants into the atmosphere in a given area remains constant from day to day; the degree of air pollution may vary widely because of differences in meteorological conditions. In a specified place the emission of pollutants may be the same but it is the weather that can trigger an air pollution episode.

The important meteorological parameters that influence air pollution can be classified into primary parameters and secondary parameters.

Primary parameters are:

1. Wind direction and speed
2. Temperature
3. Atmospheric stability
4. Mixing height

Secondary parameters are:

1. Precipitation
2. Humidity
3. Solar radiation
4. Visibility

The parameters vary widely as a function of latitude, season and topography.

Just as weather affects the severity of air pollution, air pollution, may, in turn, affect weather conditions. Air pollution may influence the weather in several ways. Visibility may be reduced, fog frequency and duration may be increased and the incoming solar radiation may be decreased, particularly in the ultra-violet end of the spectrum.

#### 3.1.1 Wind Direction and Speed

The direction and speed of surface winds govern the drift and diffusion of

air pollutants discharged near the ground level. The higher the wind speed at or near the point of discharge of pollution, the more rapidly are the pollutants carried away from the source. The pollutants so dispersed will not exist at the same concentration but will rapidly be diluted with greater and greater volumes of air. On the other hand, when wind speeds are low, pollutants tend to be concentrated near the area of discharge and the longer the periods of such light winds, the greater will be the concentration of pollutants. Further, gustiness, a very important characteristic of surface winds is directly proportional to its speed and determines the extent to which the pollutants are mixed and diluted with the surrounding air. Other things being equal, the concentration downwind from a source will be inversely proportional to wind speed. In rough terrain, it cannot be assumed that the wind direction and speed near the source govern the subsequent motion of the contaminants. Hills may deflect the air flow either horizontally, vertically, or both, the amount of deflection depending on the vertical stability of the atmosphere. In valleys, the winds carrying a pollutant tend to flow either up or down the valley, following its meanderings. The deeper the valley, the more pronounced is this channelling effect.

### 3.1.2 Atmospheric Stability and Temperature Inversions

In well mixed air which is dry, for every 1000 ft (300 m) increase in altitude, the temperature decreases by about  $3.3^{\circ}\text{F}$  (about  $1.8^{\circ}\text{C}$ ). This vertical temperature gradient is known as the 'lapse rate' and the value given is the normal lapse rate. When the reverse or negative lapse rate occurs, a dense cold stratum of air at ground level gets covered by lighter warmer air at higher level. This phenomenon is known as 'inversion'. During inversion, vertical air movement is stopped and pollution will be concentrated beneath the inversion layer, i.e., in the denser air at ground level. As a result, during temperature inversion, the atmosphere is stable and very little turbulence or mixing takes place. Under such conditions, pollutants in the air do not disperse.

Inversion is a frequent occurrence in the autumn and winter months and the accumulation of smoke and other contaminants further aggravates pollution by preventing the sun's rays from warming the ground and the adjacent air. Fog is commonly associated with inversions, because the temperature of the air at ground level falls below the dew point of the water vapour in the air. Narrow valleys are favourable to inversions since horizontal air movement is restricted. At the time of inversions, visibility is greatly reduced and contaminants are at a maximum.

#### *Types of Inversion*

- (a) Radiation inversion: It usually occurs at night, when the earth loses heat by radiation and cools the air in contact with it. If the air is moist and its temperature is below the dew point, fog will form. The cool air stratum is covered by warmer air, and the vertical movement is stopped until the

sun warms the lower air, next morning. This type of inversion is more common in winter than in summer because of the longer nights. Valley areas, because of the restriction of horizontal air movement by surrounding high ground, may frequently have such inversions.

In India, because of intense solar heating of the ground, inversions are broken within a few hours after sunrise. However, simultaneous occurrence of fog or mist prolongs the duration of inversion by cutting out sunlight reaching the ground.

(b) Subsidence inversion: It occurs at modest altitudes and often remains for several days. It is caused by sinking or subsiding of air in anti-cyclones (high pressure areas surrounded by low pressure areas). The air circulating around the area descends slowly at the rate of about 1000 m per day. As the air sinks, it is compressed and gets heated to form a warm dense layer. This acts as a lid to prevent the upward movement of contaminants. The inversion height may vary from the ground surface to 1600 m. When it drops to less than 200 m, extreme pollution occurs.

Some times both radiation inversion and subsidence inversion may occur simultaneously. Such a phenomenon is known as 'double inversion'.

#### *Adiabatic Lapse Rate*

The change of air temperature with height has a profound influence on the upward lift of the air pollutants discharged into the atmosphere and hence on their ultimate dispersion and dilution. The lapse rate of a parcel of dry air as it moves upward in a hydrostatically stable environment and expands slowly to lower environmental pressure without exchange of heat, is known as the 'adiabatic lapse rate'. The dry adiabatic lapse rate is  $0.98^{\circ}\text{C}/100\text{ m}$ . Under conditions of adiabatic lapse rate, a smoke plume will rise directly into the atmosphere by virtue of low density because of higher temperature until it reaches air of similar density. In many situations, however, because of external heating or cooling effects, the lapse rate may be greater or less than the adiabatic rate. The two most important conditions from the point of air pollution are the super adiabatic lapse rate (rate more than adiabatic) and the negative lapse rate (inversion). On a clear summer day, rapid heating of the earth by the sun warms the air near the surface, to the point where the lapse rate is superadiabatic. Under this condition the atmosphere is said to be in unstable equilibrium, and marked vertical mixing of the air results. This is a condition when pollutants are dispersed rapidly.

#### **3.1.3 Mixing Height**

The fourth, primary meteorological parameter is the mixing height. It can be defined, as that height above the earth's surface to which related pollutants will extend, primarily through the action of atmospheric turbulence. It is usually related to one or more of the three factors: wind direction,

wind speed, and wind turbulence. Under certain circumstances, it may be related to all three.

### 3.1.4 Precipitation

Rainfall or precipitation exerts a two-fold cleansing action on the pollutants discharged into the atmosphere. It accelerates the deposition of particulate matter on the ground and hence its removal from the atmosphere. It also helps to remove the concentration of gaseous pollutants which are soluble in water. The washout by precipitation of air-borne radioactive wastes is a matter of particular concern. Precipitation can be determined by using various types of rain gauges.

### 3.1.5 Humidity

The moisture content of the atmosphere influences the corrosive action of the air pollutants and indicates the potentiality for fog formation in relation to the degree of air pollution. Of the various means by which humidity may be expressed, the relative humidity is most frequently used in air pollution studies.

### 3.1.6 Solar Radiation

Depending on the location, solar radiation can have a pronounced effect on the type and rate of chemical reactions in the atmosphere. The photochemical smog formation at Los Angeles is a typical example of the effect of solar radiation on air pollution.

The application of these meteorological factors may be considered in the control of pollution from an industrial plant, in the selection of its location, in the design of equipment and in its day-to-day operation. In addition, these factors are to be taken into account in laying out zones for industrial use, in identifying causal factors in existing pollution problems and in establishing air quality criteria. The influence of both regional and local weather should be considered.

## 3.2 Methods for Measurement of Meteorological Variables

A meteorological instrument must possess an acceptable degree of accuracy and sensitivity. Also, it should be simple and durable. In our country the National Environmental Engineering Research Institute (NEERI) has developed some devices for measuring the meteorological variables.

### 3.2.1 Wind Direction Recorder

The patented instrument of the NEERI for measuring wind direction is a simple one, which employs the conventional wind vane to sense the

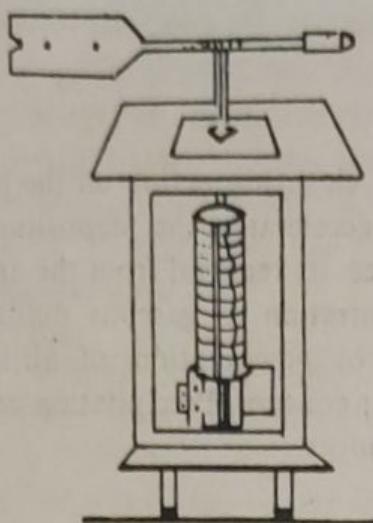


Fig. 3.1 Wind direction recorder

direction. It is automatic and operated mechanically without any power supply. The instrument continuously records on an attached chart the direction of the wind with time (Fig. 3.1).

#### *Surface Wind Direction*

There are four main types of wind vanes for measuring direction

1. Flat plate vane
2. Splayed vane
3. Aerofoil vane
4. Running average anemograph

**Flat plate vane:** In this type the sensing element which governs the azimuth angle of a vertical shaft specifying the wind direction, is a vertical plate which is mounted at one end of a horizontal rod. There is a counter weight at the other end of the horizontal rod. The rod is fastened to the vertical shaft. Wind pressure acting on the flat plate keeps the counter weight heading into the wind.

**Splayed vane:** In this instrument, two flat plates which are joined at a small angle at one end of a horizontal rod act as the wind direction sensor.

**Aerofoil vane:** In this instrument the vane has an aerofoil cross-section, with the span often being three or four times the chord.

**Running average anemograph:** It is often advantageous to be able to directly obtain a recording of the running average of the wind speed or direction or both. In averaging the wind direction, a difficulty arises from the discontinuity  $360^\circ - 0^\circ$  as the wind direction fluctuates around north. An anemograph which automatically produces the running averages of both wind speed and direction has been developed.

#### *Wind Direction Aloft*

The wind direction at the height of a plume from one or more stacks is important in some investigations. All the available following methods discussed involve considerable time and effort.

(a) **Pilot balloons (Pibals):** In this method a small balloon inflated with hydrogen or helium is left aloft and the direction of the wind aloft is determined by tracking the balloon by means of one or more theodolites on the ground. The average wind direction is obtained using triangulation techniques at successive height intervals. The pilot balloon technique of determining wind aloft is of limited value because the balloon may be lost with low cloud, fog or smoke.

(b) Tetroons: A tetroon is a constant volume Mylar balloon in the shape of a tetrahedron which is kept in a zero lift condition and carried by the wind in an almost horizontal direction. Zero lift balloons are produced by filling pilot balloons with a mixture of two gases, one more dense and the other less dense than air. As the mixture of gases leaks from the balloon, the loss of the heavier gas causes a decrease in its weight. Thus an approximate mixture of gases will keep the balloon in a zero lift or balanced condition for lengthy periods of time. Such a balloon, when accurately tracked, acts as a sensor for wind direction. The advantage of this type of balloon lies in the fact that it can indicate wind trajectories near cities, over shorelines and in valleys where complicated patterns of airflow are commonly observed. If substantial distances are to be tracked, a radar installation with a transponder suspended from the tetroon will be required which is an expensive method.

(c) Kite balloons: A kite balloon is an elongated captive balloon with fins at one end. It acts as an ordinary captive spherical balloon in light winds and as a kite in stronger winds, thus maintaining altitude under both conditions. The azimuth angle of the horizontal projection of the tethering cable is measured at the ground to determine the wind direction at the height of the balloon. The inflating gas lost by slow leakage is replaced by refilling it at intervals.

(d) Radio and radar: In the radio method, a small radio transmitter is carried aloft by a freely rising balloon and is tracked. With the radar system, pulses of electrical energy emitted by the radar are reflected back to it by a target carried by the free balloon. The distance to the target as well as azimuth and elevation angles are measured by the system. This gives more accurate results than the radio direction finder. However, operation and maintenance costs of radio and radar theodolites are prohibitively high.

(e) Smoke trails: Information on wind directions aloft may be obtained by finding at intervals the position in space of smoke trails released above the ground by a rising rocket or an aeroplane. However, observations in fog, smoke, or at night, are not possible. Also, this method requires more operating personnel than the pilot balloon method.

### 3.2.2 Wind Speed Recorder

Instruments for measuring wind speed are called anemometers. If they are recording instruments they are known as anemographs. The most common type is the cup anemometer. The rate of rotation of the shaft to which the cups are attached indicates the wind speed and this is transmitted to a recorder or an indicating panel by either mechanical, optical or electrical means.

The NEERI has developed and patented a wind speed recorder (Fig. 3.2). In the instrument a four cup rotor is employed to sense the wind. The motion of the cup is transferred after reducing its speed by a gear system,

photochemical smog formation takes place. Instruments used to measure the radiant energy from the sun are pyrheliometer, solarimeter and chemical actinometer.

### 3.3 Plume Behaviour

Plume refers to the path and extent in the atmosphere of the gaseous effluents released from a source, usually a stack.

The behaviour of a plume emitted from any stack depends on localized air stability. Typical situations as shown in the Fig. 3.5, are generally encountered in the lower atmosphere (less than 300 m above ground). Effluents from tall stacks, are often injected to an effective height of several hundred metres above ground because of the cumulative effects of buoyancy and velocity on plume rise. Other factors influencing plume behaviour

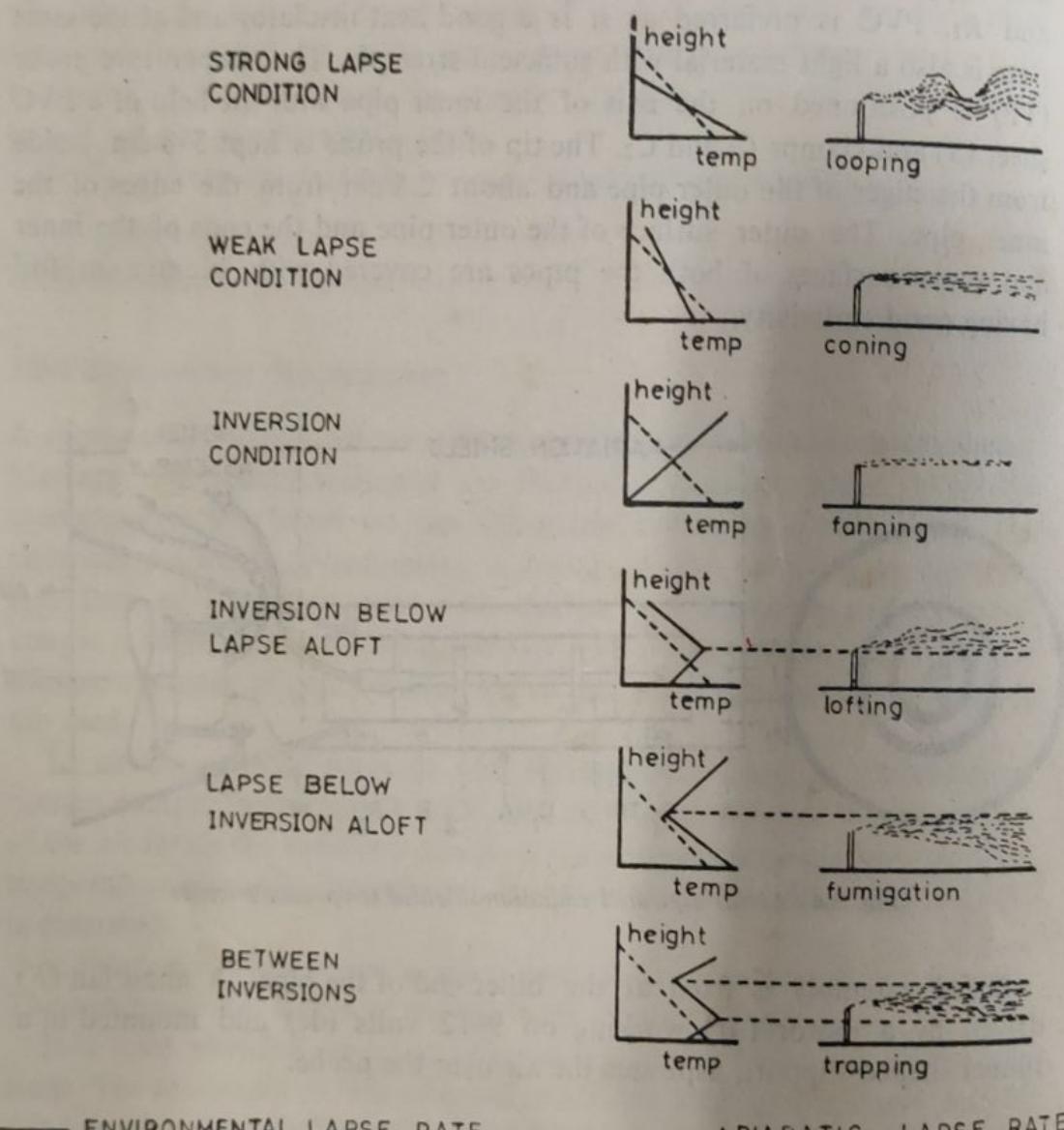


Fig. 3.5 Types of plume behaviour

are the diurnal variations in the atmospheric stability and the long term variations which occur with changing seasons.

Six types of plume behaviour are shown in Fig. 3.5. The spread of the plume is directly related to the vertical temperature gradient as shown on the left hand side of the figure.

1. Looping: It is a type of plume which has a wavy character. It occurs in a highly unstable atmosphere because of rapid mixing. The high degree of turbulence helps in dispersing the plume rapidly but high concentrations may occur close to the stack if the plume touches the ground.

2. Coning: It is a type of plume which is shaped like a cone. This takes place in a near neutral atmosphere (adiabatic condition) when the wind velocity is greater than 32 km/h. However, the plume reaches the ground at greater distances than with looping.

3. Fanning: It is a type of plume emitted under extreme inversion conditions. The plume, under these conditions will spread horizontally, but little, if at all vertically. Therefore, the prediction of ground level concentrations is difficult here.

4. Lofting: Lofting occurs when there is a strong lapse rate above a surface inversion. Under this condition, diffusion is rapid upward, but downward diffusion does not penetrate the inversion layer. Under these conditions, emissions will not reach the surface.

5. Fumigation: It is a phenomenon in which pollutants that are aloft in the air are brought rapidly to ground level when the air destabilizes.

6. Trapping: This refers to conditions where the plume is caught between inversions and can only diffuse within a limited vertical height.

The lofting plume is the most favourable with respect to minimising air pollution. The fumigating and trapping plumes are very critical from the point of ground level pollutant concentrations.

The observation of these visible smoke plumes is a useful practice to determine locations at which to take air samples. The knowledge of the characteristics of plumes is also helpful in dealing with invisible pollutants. However, in observing a plume, care should be taken to avoid optical illusions (for example, a plume may be visible for several kilometres yet not extend upward for a small fraction of a kilometre). For this, viewing simultaneously or successively from two points at right angles from the plume may be useful.

Various types of the plumes and their characteristics, occurrence and related weather conditions, etc., are shown in Table 3.1.

### 3.4 Single Stack and Multiple Source Pollution

Air pollution caused by effluents from a single or small group of stacks is a local problem. Effluent concentrations of concern generally occur at

Table 3.1 Various Types of Plumes and their Characteristics

Type of plume	Description of visible plume	Typical occurrence	Temperature profile and stability	Associated wind and turbulence	Dispersion and ground contact
Looping	Irregular loops dissipates in patches and relatively rapidly with distance.	During day time with clear or partly cloudy skies and intense solar heating.	Adiabatic or super adiabatic lapse rate. Unstable.	Light winds with intense thermal turbulence.	Disperses rapidly with distance, large probability of high concentrations sporadically at ground relatively close to the stack.
Cowing	Cone shaped with horizontal axis, dissipates further downwind than looping plume.	During windy conditions, day or night. Layer type cloudiness favoured in day.	Lapse rate between dry adiabatic and isothermal. Neutral or stable.	Moderate to strong winds. Turbulence largely mechanical rather than thermal.	Disperses less rapidly with distance than looping plume, large probability of ground contact some distance downwind. Concentration less but persists longer than looping plumes.
Fanning	Narrow horizontal fan. No vertical spreading for kms downwind. If effluent is warm, plume rises slowly, then drifts horizontally.	At night and in early morning, any season, usually favoured by light winds.	Inverted and isothermal lapse rate. Very stable.	Light winds. Very little turbulence.	Disperses slowly, concentration aloft high at relatively great distance downwind, small probability of ground contact, though increase in turbulence can result in ground contact.
Lofting	Loops or cone with well defined bottom. Diffuses to top.	During change from lapse to inversion condition, usually near sunset on fair days.	Adiabatic lapse rate at stack top and above. Inverted below stack. Lower layer stable, upper layer neutral or unstable.	Moderate winds and considerable turbulence aloft, very light winds and little turbulence in layer below.	Probability of ground contact is small unless inversion layer is shallow, considered to be the best condition for dispersion since pollutants are dispersed in upper air with small probability of ground contact.
Fumigation	Fan or cone with well defined cone and dragged or diffused bottom.	During change from inversion to lapse condition, may occur with sea breeze in late morning or early afternoon.	Adiabatic or super adiabatic lapse rate at stack top and below. Isothermal or inverted lapse rate above. Lower layer. unstable or neutral upper layer.	Winds light to moderate aloft and light below. Thermal turbulence in lower layer, little turbulence in upper layer.	Large probability of ground contact in relatively high concentration especially after plume has stagnated aloft.

distances ranging from the immediate vicinity of the stack to those of the order of several kilometres. At greater downwind distances, plumes formed by stack effluents become so diluted by diffusion in the ambient atmosphere, that concentrations may become negligibly small.

The combined effect of a large number of stack effluents spread over a large area (usually urban) produces a different type of air pollution problem which may have its principal area of concern at much greater distances. While the local pollution from any one stack may not be a problem, the combined effect of a large number of stacks produces serious urban pollution.

### 3.5 Wind Rose

A wind rose is defined as, "Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location, over a considerable period". In other words, the wind rose shows the prevailing direction of wind.

The most common form consists of a circle from which eight or sixteen lines emerge, one for each direction. The length of each line is proportional to the frequency of wind from that direction and the frequency of calm conditions is entered in the centre. There are many variations in the construction of wind roses. Some indicate the range of wind speeds from each direction, and some relate wind direction with other meteorological conditions.

Wind roses may be constructed from the data obtained over a given time period such as a particular month or season or a year. In constructing or interpreting wind roses, it is necessary to keep in mind the meteorological convention that wind direction refers to the direction from which the wind is blowing. A line or bar extending to the north on the wind rose indicates the frequency of winds blowing from the north.

The wind rose diagram is prepared using an appropriate scale to represent percentage frequencies of wind directions and appropriate index shades, lines etc., to represent various wind speeds. Observations corresponding to wind speed below 1 km/h are recorded as calm (Fig. 3.6).

Special wind roses are sometimes constructed like:

1. Precipitation wind rose
2. Smoke wind rose
3. Sulphur dioxide wind rose
4. Hydrocarbons wind rose

Instead of wind speed the parameters of precipitation, smoke, sulphur dioxide, hydro carbons etc. are attached to the wind direction. These are known as 'Pollution Roses'.

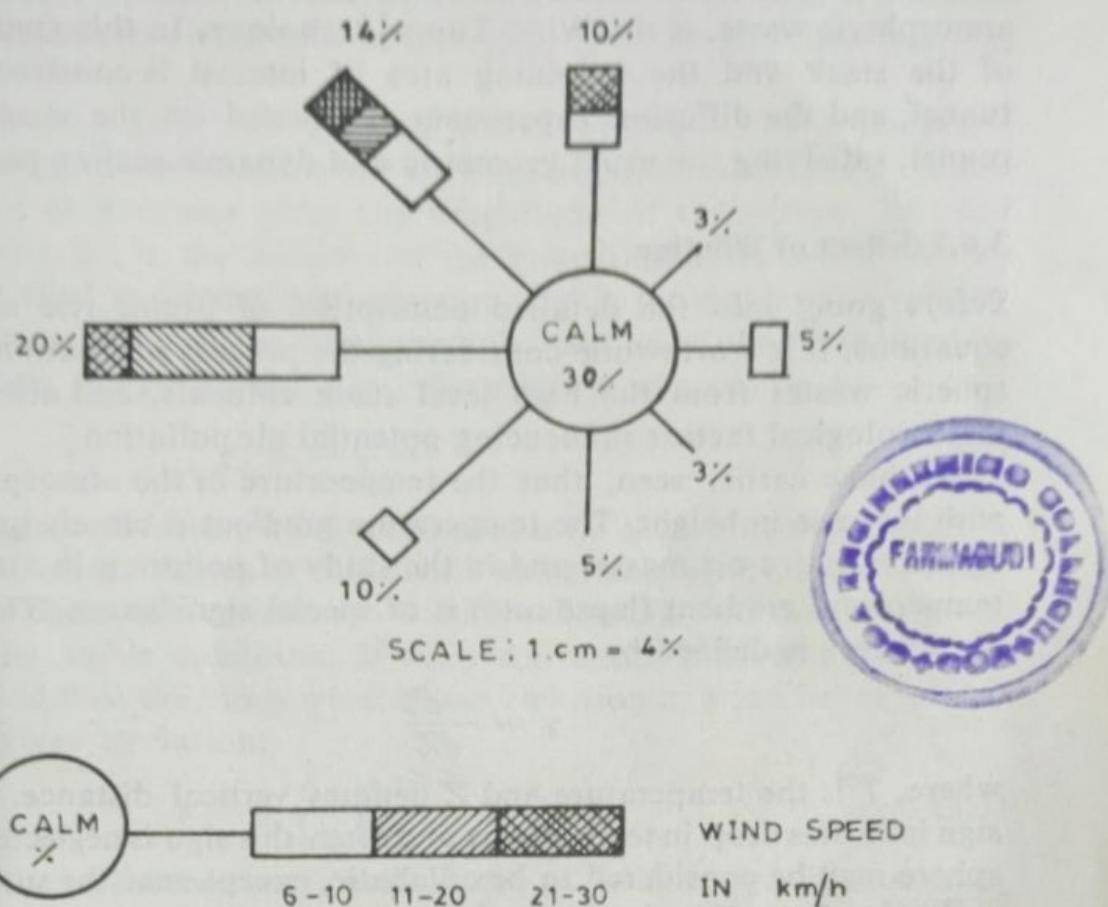


Fig. 3.6 Wind rose construction

### 3.6 Stack Effluent Dispersion Theories

The dilution of atmospheric wastes from elevated stacks is considered to occur in two stages, namely, plume rise and dispersion. In the first stage, the hot plume from the stacks goes up to a certain distance (defined as 'plume rise') into the atmosphere, due to buoyancy and momentum. Subsequently in the second stage, the plume spreads both vertically and horizontally by the dispersion process. The latter phase, i.e., the phase of pollutant dispersion can be described by the mathematics of diffusion, and has been the subject of considerable theoretical and experimental work by many workers in this field. On the other hand, all the plume rise equations are mostly empirical in nature, and none is uniformly accepted. However, the available theoretical and empirical equations can be effectively utilized to estimate the concentration of pollutants downwind from an emission source. These theories and equations, involving plume temperature, rate of emission, stack parameters such as height and diameter, meteorological factors like wind speed and direction, and the atmospheric stability, as well as the parameters representing, the topography of the region, have been employed successfully in many stack design and pollution control problems.

It has been reported that in the direction of wind, the maximum concentration is attained at a distance  $X_m$  ranging from 10–40 times the stack height.

The empirical formula for the stack height emitting maximum concentration of pollutants is given as follows

$$C_{\max} = \frac{AFMm}{H^2} \left( \frac{n}{V \cdot t} \right)^{1/3} \quad (3.13)$$

where,

$C_{\max}$  = Maximum concentration of pollutants

$A$  = Coefficient, depends upon atmospheric condition

= 200 for Indian conditions

$F$  = Coefficient, depends upon dust precipitation efficiency, ranges from 0.8 to 0.95

$M$  = Quantity of flue gases in g/s

$m$  = Coefficient depends upon velocity of flue gases

$H$  = Height of stack or chimney in m

$n$  = Number of emitting sources

$V$  = Volume of gases leaving the chimney in cu. m/s.

$t$  = Difference in temperature between flue gases and atmospheric temperature at the top of the stack.

This formula is in use in the USSR and coefficients are being derived for Indian conditions.

### Example

A factory uses 2,00,000 litres of furnace oil (specific density 0.97) per month. If for one million litres of oil used per year, the particulate matter emitted is 3.0 tonnes per year,  $\text{SO}_2$  emitted is 59.7 tonnes per year,  $\text{NO}_x$  emitted is 7.5 tonnes per year, hydrocarbons emitted are 0.37 tonnes per year, and carbon monoxide emitted is 0.52 tonnes per year, calculate the height of the chimney required to be provided for safe dispersion of the pollutants.

As per emission regulations (July 1984) part I published by the Central Board for Prevention and Control of Water Pollution, New Delhi, the chimney height is to be calculated according to the formula:

$$H = 74(Q)^{0.27} \quad (3.14)$$

where

$Q$  = particulate matter emission in tonnes per hour

$H$  = height of chimney in metres

The particulate emission is equal to 3.0 tonnes per million litres of oil per year. Consumption of oil is equal to

$$\begin{aligned} 2,00,000 \times 12 &= 24,00,000 \text{ l/year} \\ &= 2.4 \text{ million l/year} \end{aligned}$$

Therefore,

$$\begin{aligned}\text{Total particulate emission} &= 2.4 \times 3.0 = 7.2 \text{ tonnes per year.} \\ &= \frac{7.2}{300 \times 24} \text{ tonnes per hour (assuming 300} \\ &\quad \text{working days and 24 hours per day).}\end{aligned}$$

Now,

$$\begin{aligned}H &= 74 \left( \frac{7.2}{300 \times 24} \right)^{0.27} \\ &= 11.47 \text{ m}\end{aligned}$$

The height of the chimney for effective dispersion of  $\text{SO}_2$  is to be calculated as per the formula  $H = 14(Q)^{0.3}$  (as given in Sec. 19.5 under guidelines for minimum stack height)  
where,

$Q = \text{SO}_2$  emission in kg/h

$H = \text{Height of chimney in metres}$

$$\begin{aligned}Q \text{ in the example} &= 59.7 \times 2.4 = 144 \text{ tonnes per year} \\ &= 20 \text{ kg/h}\end{aligned}$$

$$\begin{matrix}144 \times 10^3 \\ 300 \times 24\end{matrix}$$

$$\text{Therefore } H = 14(20)^{0.3} = 34.4 \text{ m}$$

So, adopt a height of 34.4 metres.

(Since the emission of  $\text{SO}_2$  is much more than that of  $\text{NO}_x$ ,  $\text{CO}$ , and Hydrocarbons, the calculation of stack height is done based on  $\text{SO}_2$  emission data only).

### 3.6.7 Scope for Future Work

Many experimental and theoretical works are in progress to investigate the complicated atmospheric structure, both near the ground and well above the ground. Many interesting meteorological features, from the point of atmospheric pollution, are now recognised. In view of the importance of many meteorological factors and topographical features besides the stack geometry, and also in view of the increased available memory capacities of digital computers, there is no reason why we should not take up the numerical method of solution of the problem of atmospheric pollution thereby avoiding any unnecessary simplification of the problem.

## QUESTIONS

1. List out the meteorological factors influencing air pollution.
2. Explain the role of meteorological elements in the dispersion of air pollutants in the atmosphere.
3. Explain the cause and effects of 'inversion of atmosphere'.
4. Explain stable and unstable atmosphere and inversion of the atmosphere.
5. Explain the following atmospheric conditions:
  - (a) Super-adiabatic
  - (b) Sub-adiabatic

### 36 Air Pollution

- (c) Neutral
- (d) Inversion

How do they influence the dispersion of pollutants in the atmosphere?

6. With the help of neat sketches, explain the working of
  - (a) Wind speed recorder
  - (b) wind direction recorder.
7. Define a wind rose. Explain the importance of wind roses in air pollution studies.
8. Explain the terms
  - (a) Environmental lapse rate
  - (b) Adiabatic lapse rate
  - (c) Wind rose
9. Describe with neat sketches, how different atmospheric conditions give rise to different kinds of plumes.
10. Write explanatory notes on
  - (a) Dispersion models
  - (b) Estimation of plume rise
  - (c) Wind tunnel techniques for the study of atmospheric diffusion
  - (d) Calculation of stack height
11. Write short notes on:
  - (a) Inversions
  - (b) Wind rose
  - (c) Lapse rate
  - (d) Atmospheric dispersion
  - (e) Plume behaviour

# 5

## Effects of Air Pollution on Human Health

### 5.1 Introduction

Air pollution is one of the greatest environmental evils. The air we breathe has not only life-supporting properties but also life-damaging properties. Under ideal conditions the air we inhale has a qualitative and quantitative balance that maintains the well-being of man. But when the balance among the air components is disturbed, or in other words, if it is polluted, it may affect human health.

An average man breathes 22,000 times a day and takes in 16 kg of air each day. It far exceeds the consumption of food and water. It has been estimated, that a man can live for five weeks without food and five days without water, but only for five minutes without air.

All the impurities in the inhaled air do not necessarily cause harm. Depending upon the chemical nature of the pollutants, some may be harmful when present in the air in small concentrations and others only if they are present in high concentrations. The duration of exposure of the body to polluted air is also an important factor. Therefore, the prime factors affecting human health are:

1. Nature of the pollutants
2. Concentration of the pollutants
3. Duration of exposure
4. State of health of the receptor
5. Age group of the receptor

Generally speaking, susceptibility to the effects of air pollution is great among infants, the elderly, and the infirm. Those with chronic diseases of the lungs or heart are thought to be at great risk. Pre-school and school children appear to be both sensitive and specifically reactive to air pollution health effects. Another point to be noted is that the effect of air pollution on human health is worst during the winter season, when pollution levels reach a climax.

An objectionable odour, visibility reduction, eye irritation or vegetation damage are useful guides to the likelihood or severity of health effects. A grey pall over a city or an industrial area can have a depressing effect and impair the enjoyment of life. There is no doubt, however, that the urgency

with which steps are taken to improve air quality will depend very much on how serious the risk of ill health from air pollution is thought to be.

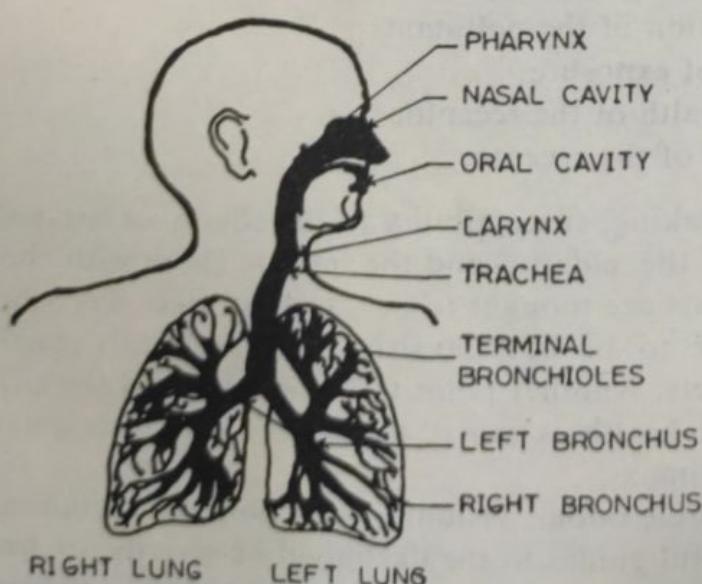
Table 5.1 gives some of the disastrous air pollution events in the world.

**Table 5.1 Air Pollution Episodes**

S. No.	Month and year	Place	Mortality
1.	December, 1930	Meuse Valley (Belgium)	63
2.	October, 1948	Donora (Pennsylvania)	20
3.	November, 1950	Poza Rica (Mexico)	22
4.	December 1952	London	4000
5.	November, 1953	New York	220
6.	January, 1956	London	1000
7.	December, 1957	London	750
8.	December, 1962	London	700
9.	January, 1963	New York	300
10.	November, 1966	New York	168
11.	December, 1984	Bhopal (India)	2000

## 5.2 Mechanism of Action of Air Pollutants

The effects of air pollution on human health generally occur as a result of contact between the pollutants and the body. Normally, bodily contact occurs at the surfaces of the skin and exposed membranes. Contact with exposed membranous surfaces is of utmost importance because of their high absorptive capacity compared to that of the skin. Air-borne gases, vapours, fumes, mist, and dust may cause irritation of the membranes of the eyes, nose, throat, larynx, tracheo-bronchial tree and lungs (Fig. 5.1).



**Fig. 5.1 Human respiratory system**

Some irritants even reach the mucosa of the digestive tract. The details of the mechanism involved is beyond the scope of this book, as greater attention has been given to the engineering aspects.

## 5.3 Health Effects

1. Eye Irritation.
2. Nose and throat irritation.
3. Irritation of the respiratory tract.
4. Gases like hydrogen sulphide, ammonia and mercaptans cause odour nuisance even at low concentrations.
5. Increase in mortality rate and morbidity rate.
6. A variety of particulates particularly pollens, initiate asthmatic attacks.
7. Chronic pulmonary diseases like bronchitis and asthma, are aggravated by a high concentration of  $\text{SO}_2$ ,  $\text{NO}_2$ , particulate matter and photochemical smog.
8. Carbon monoxide combines with the haemoglobin in the blood and consequently increases stress on those suffering from cardiovascular and pulmonary diseases.
9. Hydrogen fluoride causes diseases of the bone (fluorosis), and mottling of teeth.
10. Carcinogenic agents cause cancer.
11. Dust particles cause respiratory diseases. Diseases like silicosis, asbestos, etc., result from specific dusts.
12. Certain heavy metals like lead may enter the body through the lungs and cause poisoning.

### 5.3.1 Effect of Radioactive Fallout

The biological effect of radiation may be somatic or genetic damage. In somatic damage, the exposed individual is affected, while in genetic damage the future generations become the victims.

Radioactive fallout from testing of nuclear weapons causes:

- (a) Cancer
- (b) Shortening of life span
- (c) Genetic effects or mutation

One significant point we have to note about the effect of radioactive fallout is, it causes long range effects affecting the future of man and hence the future of our civilization.

## 5.4 Investigation of Health Effects of Air Pollutants

Three methods are available for determining the effect of various pollutants on people. They are:

1. Experimental exposures of men and animals
2. Clinical studies
3. Epidemiology

The experimental exposure of different types of animals under controlled conditions to various concentrations and dosages of air pollutants, can give valuable information regarding the mode of action of a pollutant and its effects. Of course, results must be subjected to rigorous statistical analysis. But the main problem here is, the extrapolation of results to human population.

Experimental exposures of men should be limited to concentrations and dosages of pollutants that will not result in serious illness. Types of effects noticed and measured include detection of odour, irritation of eyes, nose and throat, change in pulse rate, breathing frequency, reduction in physical activity and many other physiological responses.

Clinical studies mainly involve observations made on subjects who are or were exposed to atmospheric pollutants under uncontrolled conditions. Studies of truck drivers, traffic policemen, factory workers and other occupational groups may give valuable information. Also, patients visiting physicians to complain of symptoms supposedly caused by living in polluted areas may upon observation yield clinical data of great importance. Further, information has been collected by the follow up of the acute air pollution episodes. The data collected has indicated a relationship between air pollution and disease, particularly pulmonary disease.

In epidemiological studies, the relationships between the distribution of specific diseases in a human population and the factors that determine the distribution are found out. For example, one may compare morbidity records, mortality records, hospital admissions, absenteeism, and other health related data from various geographical areas with levels of air pollutants in the same areas to determine a correlation, if any. To avoid misinterpretation, the population under study must be carefully observed for smoking habits, occupational exposures, and any other factor that might prejudice the results of the study.

## 5.5 Specific Pollutants

### 5.5.1 Sulphur Dioxide

Sulphur dioxide is an irritant gas which affects the mucous membranes when inhaled. Under certain conditions, some of the air-borne sulphur dioxide gas is oxidised to sulphur trioxide. Each of these two gases, in the

presence of water vapour or water, forms sulphurous and sulphuric acid respectively. Sulphur trioxide is a very strong irritant, much stronger than sulphur dioxide, causing severe bronchospasms at relatively low levels of concentration.

### 5.5.2 Carbon Monoxide

Carbon monoxide has a strong affinity for combining with the haemoglobin of the blood to form carboxyhaemoglobin, COHb. This reduces the ability of the haemoglobin to carry oxygen to the body tissues. CO has about two hundred times the affinity of oxygen for attaching itself to the haemoglobin, so that low levels of CO can still result in high levels of COHb. Carbon-monoxide also affects the central nervous system. It is also responsible for heart attacks and a high mortality rate.

### 5.5.3 Oxides of Nitrogen

Of the seven oxides of nitrogen known to exist in the ambient air, only two are thought to affect human health. These are nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). While some questions remain about haemoglobin reactions with oxides of nitrogen, there is no positive evidence that nitric oxide exposure is a health hazard associated with community air pollution.

Nitrogen dioxide is known to cause occupational disease. Among occupations with NO<sub>2</sub> hazards are the manufacture of nitric acid, exposures of farmers to silage that has had high nitrate fertilisation, electric arc welding, and mining utilising nitrogen compounds as explosives. It is estimated that eye and nasal irritation will be observed after exposure to about 15 ppm of nitrogen dioxide and pulmonary discomfort after brief exposures to 25 ppm of nitrogen dioxide.

### 5.5.4 Hydrogen Sulphide and Mercaptans

Hydrogen sulphide is a foul smelling gas. It is well known for its rotten egg like odour. Exposures to hydrogen sulphide for short periods can result in fatigue of the sense of smell.

*Note down* Other sulphur compounds that are of interest in air pollution mainly because of their strong odours are methyl mercaptan (CH<sub>3</sub>SH) and ethyl mercaptan (C<sub>2</sub>H<sub>5</sub>SH). But it has been reported that at the concentrations at which they are odour nuisances, they have no other effect on human health. In fact, mercaptans are often added to natural or manufactured gas supplies so that leakage of gas will be noticed.

### 5.5.5 Ozone

Ozone is a gas that has an irritant action in the respiratory tract, reaching much deeper into the lungs than the oxides of sulphur.

### 5.5.6 Fluorides

Fluorides present in air, range from those which are extremely irritant and

corrosive like hydrogen fluoride to relatively non-reactive compounds. But, fluorine is a cumulative poison even under condition of prolonged exposure and in sub-acute concentrations.

#### **5.5.7 Lead**

The main source of lead in urban atmospheres is the automobile. It creates urban concentration of inorganic lead of about  $1-3 \mu\text{g}/\text{m}^3$ , with high values in areas of heavy traffic. Inorganic lead acts as an agent which causes a variety of human health disorders. The effects include gastro-intestinal damage, liver and kidney damage, abnormalities in fertility and pregnancy, and mental development of children gets affected.

#### **5.5.8 Hydrocarbon Vapours**

Some of the hydrocarbon vapours in the atmosphere have health implications. The effect of formaldehyde is primarily irritating. It is a major contributor to eye and respiratory irritation caused by photochemical smog.

#### **5.5.9 Carcinogenic Agents**

Carcinogenic agents are responsible for cancer. For example, the poly-cyclic organic compound, 3, 4-benzpyrene. The origin of these compounds is in the incomplete combustion of hydrocarbons and other carbonaceous materials. They are also reported to be present in exhaust discharges from I.C. engines. In addition to poly-cyclic organic compounds, it has been found that some aliphatic hydrocarbons are also carcinogenic.

#### **5.5.10 Insecticides**

Insecticides are not only harmful for insects but also poisonous for man, e.g., DDT (Dichloro diphenyl trichloroethane). They can affect the central nervous system and may attack other vital organs. In fact, DDT has been found in mother's milk in western countries and even in our own country. Hence, the use of DDT has been banned in the USA. The United Nations Environment Programme (UNEP) has warned against the undesirable effects of indoor spraying of DDT. It has also been reported that indoor spraying affects domestic livestock.

According to a study conducted at the Industrial Toxicology Research Centre, Lucknow (India), the accumulation of pesticides in the environment due to their growing use for agricultural purposes can also cause premature labour and abortion, due to high concentration of pesticides in the body of expectant mothers.

#### **5.5.11 Radioactive Isotopes**

The important radioactive isotopes that may reach ambient air are Iodine 131, Phosphorous 32, Cobalt 60, Strontium 90, Radium 226, Carbon 14,

Sulphur 35, Calcium 45 and Uranium. The major sources of radioactive air pollutants are:

- (a) Nuclear reactors
- (b) Experimental accelerators
- (c) Scientific and medical use of radioactive isotopes
- (d) Agricultural and industrial use of radioactive isotopes as tracers, and
- (e) Testing of nuclear bombs in the atmosphere.

The serious health effects are anaemia, leukaemia and cancer. Radioactive isotopes also cause genetic defects and sterility, as well as embryo defects and congenital malformations. It also shortens the life span of an individual.

#### 5.5.12 Allergic Agents

It is generally recognised by medical personnel that the air we breathe is the natural carrier of many microscopic organic materials which may act as allergens. Our body reactions to such allergens occur mainly in the skin and the respiratory tract. Organic allergens have their origins in living things like plants (pollen grains), yeasts or moulds, or in animal hair, fur, or feathers.

An interesting case in this respect, is the city of Bangalore. The garden city of Bangalore, known for its fine climate, is also known as the place of asthma for many people. The incidence of bronchial asthma is particularly high in this city. Instances have been cited where people who have never exhibited tendencies earlier, have, on coming to Bangalore, had attacks of asthma. Further, those who have had only mild attacks elsewhere experienced severe ones here. Also, it has been recorded that the percentage of asthmatics who reported relief when they left Bangalore is as high as 37.6%.

A systematic investigation of the pollen and fungal spore content of the atmosphere in Bangalore was undertaken for the first time from July 1976 to July 1978, by the Asthma Research Society. The study resulted in identification of 75 types of air-borne pollen and 120 types of spore. The pollen calendar for 1976-78 from 10 different sampling stations around Bangalore, showed that pollen grains were present all the year around in the city atmosphere. All the identified pollen types were attributed to local plants. According to the study, the pollen of parthenium was the highest in quantity (41%), followed by grass pollen (28.8%). The Cassia species (11.8%) take the next place.

The survey revealed that housewives (37.01%) and office workers (40.31%) are more susceptible to asthma attacks than industrial workers (7.11%) and retired persons (11.29%). This suggests that industrial pollutants can be almost ruled out as a causal factor for asthma and that attention should be focussed on pollen, spores and dust particles.

Although asthma is not a contagious disease, 32.27 per cent of hereditary cases came to light during the survey. But according to the Secretary of the Asthma Research Society, even though two factors (pollen and fungal spores) have been analysed for two years, final conclusions have not been drawn

# Effects of Air Pollution on Plants

## 7.1 Introduction

Air pollution has long been known to have an adverse effect on plants. At first, it was only sulphur dioxide that was considered a dangerous pollutant. Now, with the advent of various pesticides and new industrial processes, the range of harmful pollutants has multiplied tremendously. Sometimes, vegetation over 150 km away from the source of the pollutant has been found to be affected.

Industrial pollution, particularly from smelters, has caused complete destruction of vegetation in some cases e.g., at Ducktown, Tennessee. The international dispute between Canada and the United States over the damage caused by the Trail, British Columbia Copper Smelter is well known. Los Angeles smog has caused wide spread damage to some crops and forests in Southern California. In fact, many books and reports have been published in USA on air pollution injury to vegetation. In some cases, economics of the damage caused to crops and plants has been estimated. Compensation amounting to thousands of dollars has been paid for damage done to the crops. In our own country, there are many reports of the effect of pollutants like cement dust on plants.

## 7.2 Structure of a Normal Leaf

A knowledge of the structure of a leaf will help us understand why damage occurs to plants on account of air pollutants. A generalized diagram of the structure of a normal leaf is given in Fig. 7.1. If we examine a leaf, one will normally see a network of denser structures, the veins, all interconnected to the base or stem of the leaf. The leaf veins act as the transport system for water and food, just like blood vessels in animals. The leaf tissue is in layers with a skin or epidermis layers on top and bottom and the photosynthetic cells in between. The stomata are the entrances in the leaf bottom (and in some leaves in the top) through which  $\text{CO}_2$  enters to play its role in photosynthesis. These openings are protected by pairs of specialized guard cells which open and close to allow gases to enter or leave the leaf. Such gases of course, include pollutants like sulphur dioxide.

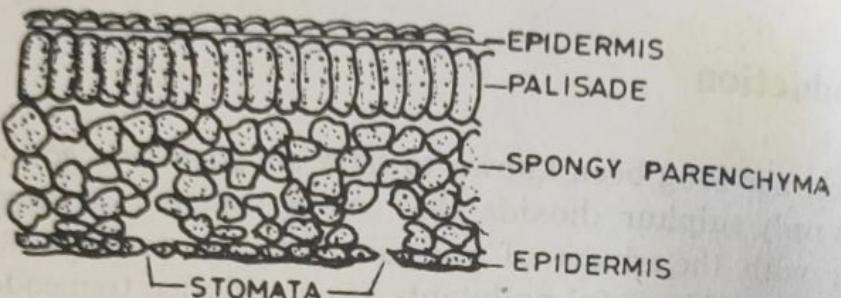
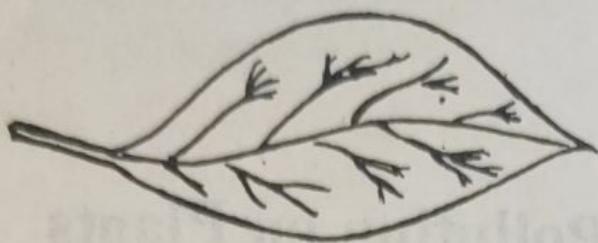


Fig. 7.1 Cross-section of a leaf

### 7.2.1 Effect of Environment on Plants

The primary factor which controls gas absorption by the leaves is the degree of opening of the stomata. When the stomata are wide open, absorption is maximum and vice versa. Consequently, the same conditions that enhance the absorption of the gas ( $\text{CO}_2$  for photosynthesis), predispose the plant to injury (by absorbing a pollutant gas like  $\text{SO}_2$ ). The conditions that cause the stomata to open are high light intensity (especially in the morning hours), high relative humidity, adequate moisture supply to the roots of the plant and moderate temperatures.

Most plants close their stomata at night and are therefore much more resistant at night than in the day time. But some plants like the potato, which do not close their stomata at night are as sensitive in the dark as in the light.

## 7.3 Air Pollutants Affecting Plants

1. Sulphur dioxide
2. Fluoride compounds (like hydrogen fluoride)
3. Ozone
4. Chlorine
5. Hydrogen chloride
6. Nitrogen oxides ( $\text{NO}$ ,  $\text{NO}_2$ , etc.)
7. Ammonia
8. Hydrogen sulphide
9. Hydrogen cyanide
10. Mercury
11. Ethylene

12. PAN (peroxy acetyl nitrate)
13. Herbicides (sprays of weed killers)
14. Smog

The above pollutants interfere with plant growth and the phenomenon of photosynthesis. Smog, dust, etc., reduce the amount of light reaching the leaf and also by clogging the stomata may reduce carbon dioxide intake to some extent and thus interfere with photosynthesis.

## 7.4 Forms of Damage to Leaves

Damage to leaves takes several forms

- |               |  |
|---------------|--|
| 1. Necrosis   | : Necrosis is the killing or collapse of tissue.   |
| 2. Chlorosis  | : Chlorosis is the loss or reduction of the green plant pigment, chlorophyll. The loss of chlorophyll usually results in a pale green or yellow pattern. Chlorosis generally indicates a deficiency of some nutrient required by the plant. In many respects, it is analogous to anaemia in animals. |
| 3. Abscission | : Leaf abscission is dropping of leaves.   |
| 4. Epinasty   | : Leaf epinasty is a downward curvature of the leaf due to higher rate of growth on the upper surface.   |

*Notes:* 1. Tissue severely injured by air pollutants often has a characteristic colour. Bleaching is associated with sulphur dioxide, yellowing with ammonia, browning with fluoride. A silvery or bronzing of the under surface of some leaves is associated with PAN injury.  
 2. Phytotoxicant is the name given to plant damaging substances.

### 7.4.1 Kinds of Injury to Plants

#### *Acute Injury*

It results from short-time exposure to relatively high concentrations, such as might occur under fumigation conditions. The effects are noted within a few hours to a few days and may result in visible markings on the leaves due to a collapse and death of cells. This leads to necrotic patterns, i.e., areas of dead tissue.

#### *Chronic Injury*

It results from long-term low level exposure and usually causes chlorosis or leaf abscission.

#### *Growth or Yield Retardation*

Here the injury is in the form of an effect on growth without visible markings (invisible injury). Usually a suppression of growth or yield occurs.

While deciding about the type of injury the plant has suffered, one must carefully distinguish between adverse effects caused by air pollution and adverse effects resulting from other factors. Plant diseases may show symptoms which are very similar to those caused by air pollution. High temperatures, poor plant care, shortage of nutrients and water may also cause an appearance which is similar to that of a plant damaged by air pollution. It may also be due to insect damage. Therefore, while diagnosing the effects of air pollution one must consider factors such as plant disease, nutrition history, weather damage, insect damage, and the nature of pollutants in the area.

## 7.5 Effects of Air Pollutants on Plants

The effects of various pollutants like sulphur dioxide, ozone, fluorides, etc., on plants is shown in Table 7.1.

**Table 7.1 Effects of Pollutants on Plants**

Pollutant	Dose	Effect
1. Sulphur dioxide	Mild	Interveinal chlorotic bleaching of leaves
	Severe	Necrosis in interveinal areas and skeletonized leaves
2. Ozone	Mild	Flecks on upper surfaces, premature aging and suppressed growth
	Severe	Collapse of leaf, necrosis and bleaching
3. Fluorides	Cumulative effect	Necrosis at leaf tip
4. Nitrogen dioxide	Mild	Suppressed growth, leaf bleaching
5. Ethylene	Mild	Epinasty, leaf abscission
6. PAN	Mild	Bronzing of lower leaf surface (upper surface normal), suppressed growth. Young leaves more susceptible

### 7.5.1 Effect of Sulphur Dioxide

Sulphur dioxide produces two types of injury on the leaves of plants—acute and chronic, depending on the concentration and period of exposure. The acute injury is characterized by the killing of marginal or interveinal areas of the leaf. Immediately after fumigation these areas will get a dull, water-soaked appearance. Subsequently they dry up and usually bleach to an ivory colour, though some species finally assume a brown or reddish-brown colour. Chronic injury is caused by the slow, long-continued absorption of sub-lethal amounts of gas or by absorption of an amount of gas somewhat less than that necessary to cause acute injury.

Sulphur dioxide is phytotoxic in concentrations above 0.1–0.2 ppm. Below

about 0.4 ppm, it tends to be oxidised in the cells as rapidly as it is absorbed, but interferences with functions such as photosynthesis is slight. Chronic injury, if any, is generally exhibited with these small concentrations.

Above about 0.4 ppm, acute injury occurs more frequently. Sometimes temporary interference with photosynthesis or 'invisible injury' can occur. However, the mechanism by which sulphur dioxide affects the plant has not yet been well understood, though various explanations have been put forth by many investigators.

### 7.5.2 Effect of Hydrogen Fluoride

Hydrogen fluoride behaves somewhat similar to sulphur dioxide except that with a few species of plants it is effective in causing lesions and interfering with photosynthesis in concentrations two or three orders less than in the case of sulphur dioxide. With most species it is up to 10 times as effective as sulphur dioxide. However, recovery of plants from the fluoride effect is much slower than from sulphur dioxide. This difference in rate of recovery is probably explained by the fact that sulphite in the leaves is rapidly oxidised to the relatively non-toxic sulphate, whereas fluorides can be removed only by the slower process of volatilization or by some obscure chemical reaction. Forage may be rendered unsafe for animal feeding if more than 50 ppm of fluorine is absorbed.

### 7.5.3 Effect of Ozone

Ozone is phytotoxic in exposures of a few hours at about 0.2 ppm. Injury due to ozone is quite different from typical smog injury. The lesions are generally confined to the upper surface. The effects of ozone on plants in mild and severe doses is indicated in Table 7.1.

### 7.5.4 Effects of various Fumigants on Plants

#### *Chlorine*

Apart from the fluorides, halogens and their compounds are relatively unimportant air pollutants which might cause injury to vegetation. However, chlorine is more toxic to vegetation than sulphur dioxide by a factor of two or three. Lesions are generally marginal and interveinal. Damage to vegetation caused by chlorine is rare, and most of the reported cases are due to accidents or excessive use of gas for sterilising.

#### *Hydrogen Chloride*

Hydrogen chloride is considerably less toxic to vegetation than sulphur dioxide. Hydrogen chloride causes first a chlorotic margin in the leaf, which may become necrotic. At higher concentrations, lesions are produced. The threshold concentration is about 10 ppm for a few hours exposure.

### *Nitric Oxides*

Injury to plants due to nitric acid vapours has been observed near factories handling large amounts of this acid. The effects include brown margins and brownish-black spots on the leaves. Concentrations of about 25 ppm will cause these effects. Nitrogen oxides are important in photochemical reactions which cause smog.

### *Ammonia*

Ammonia is a gas of intermediate toxicity. It is interesting to note that ammonia and hydrogen chloride almost have about the same toxicity.

### *Hydrogen Cyanide*

Hydrogen cyanide is used to fumigate green houses and trees in orchards for pest control. Sometimes this fumigation injures the vegetation.

### *Ethylene*

Ethylene causes injury to leaves of sensitive plants. The effects are epinasty, curling, chlorosis, leaf abscission, and growth retardation.

### *Herbicides*

Injury to sensitive vegetation may be caused in the field through careless or uncontrolled use of herbicides and pesticides. It has been reported that weedy grain fields have sometimes been sprayed when there was wind, and the spray has been carried for several kilometres in sufficient concentration to injure crops like cotton and tomatoes. Many other plants which have exhibited symptoms of injury under similar conditions are roses, cabbage, pepper, grapes and tobacco.

#### **7.5.5 Smog**

London type smog is thought to be essentially a sulphur dioxide problem. But the gaseous constituents as well as the aerosols need further evaluation.

The Los Angeles type smog is now fairly well understood, but the actual compounds that cause these effects are still unknown. Two types of smog injury to vegetation have been recognized in Los Angeles, one due to gases (smog gas) and the other due to deposition on the leaves of fog droplets (smog fog). The smog causes characteristic leaf lesions which are quite different from those produced by other pollutants, including ozone, which may be a constituent of the smog. It also causes some 'invisible' injury.

### **7.6 Sensitivity of Plants to Air Pollutants**

The sensitivity of plants to air pollutants is conditioned by many factors.

### 7.6.1 Genetic Factors

Plant response to pollutants varies between species of a given genus and between varieties within a given species. Such variation is simply a function of genetic variability as it affects the plants' morphological, physiological, and biochemical characteristics. Plants do not necessarily show similar susceptibility to different pollutants. For example, some plants are sensitive to fluoride but resistant to sulphur dioxide.

### 7.6.2 Climatic Factors

The important climatic factors affecting the response of vegetation to air pollutants are

1. Duration of light
2. Light quality (wave length)
3. Light intensity
4. Temperature
5. Humidity

### 7.6.3 Miscellaneous Factors

Soil, water, and fertility affect the sensitivity of plants to air pollutants. However, these factors have to be studied in detail before drawing any conclusions.

## 7.7 Time-Concentration Equations

The effect of concentration versus time is an important variable in assessing damage. A high dose for a short time may cause an acute injury, whereas the same total dose over a longer time may cause no visible effects at all.

The concentration-time equation may be expressed as,

$$t(C - C_0) = K \quad (7.1)$$

where,

$t$  = time in hours to produce a certain effect on a certain species

$C$  = concentration of a specific gas in ppm

$C_0$  = threshold concentration of the gas (ppm) to cause injury

$K$  = experimentally determined constant

The equation can be rewritten as

$$C = C_0 + \frac{K}{t} \quad (7.2)$$

Then plotting  $C$  versus  $\frac{1}{t}$ , we get a straight line whose intercept  $C_0$  is the threshold for injury. With the exception of some results for sulphur dioxide and ozone, sufficient data is not available at present to determine

these parameters, assuming that a linear model is accurate. The equation is based on the exposure of a plant for a single pollutant. However, in the field, exposures are usually not due to individual gases but to a mixture of pollutants whose relative concentrations change as functions of time. Thus, there are almost infinite number of possible combinations of pollutants which could be tested.

Thomas, Hendricks, and Hill (1935) generalized this equation for the alfalfa plant, for any degree of leaf destruction and any degree of susceptibility. With maximum susceptibility, three equations were given as follows:

$$t(C - 0.24) = 0.94 \text{ traces of leaf destruction} \quad (7.3)$$

$$t(C - 1.4) = 2.1 \text{ 50% leaf destruction} \quad (7.4)$$

$$t(C - 2.6) = 3.2 \text{ 100% leaf destruction} \quad (7.5)$$

## 7.8 Leaf Destruction in Relation to the Yield

Many industries that emit phytotoxic gases are located near valuable agricultural lands. If damage is done to nearby crops, the farmer is legally entitled to recover his losses (especially in countries where air pollution control legislation is in force). Therefore, an objective method is required for determining the extent of losses. Many studies have shown that for sulphur dioxide, the reduction in the yield of the crop is proportional to the percentage of leaf area destroyed. The equation is of the form

$$y = a - bx \quad (7.6)$$

where,

$y$  = yield expressed as the percentage of full yield

$x$  = percentage of leaf area destroyed

$a$  = constant (about 100%)

$b$  = Slope of yield-leaf destruction curve.

In general, the leaf destruction yield functions are straight lines, starting with 100% yield  $y$ , at 0% leaf destruction  $x$ , and ending with a definite decrease in yield at 100% leaf destruction. But from the practical point of view, the reduction in the yield is difficult to measure experimentally if leaf destruction is less than about 5%.

## 7.9 Air Pollution Injury Report

A typical air pollution injury report with respect to crops can be as follows:

Grower's name	:
Location of plants/crops	:
Suspected pollutant $\text{SO}_2, \text{O}_3,$	
HF, others (specify)	:

Suspected source/sources	:	
Crop and variety	:	
Area affected	:	Hectares
Number of plants	:	
Date/month of incidence	:	
Average % of plants affected	:	0-10, 11-30, 31-60, 61-80, 81-90, 91-99, 100
Average % of each plant affected	:	0-10, 11-30, 31-60, 61-80, 81-90, 91-99, 100
Loss in quality	:	Loss in Quantity
Estimated crop loss	:	% OR Rs.
Remarks	:	

Reporter's name

:

Date

## QUESTIONS

1. List the air pollutants affecting plants.
2. Explain the following terms with respect to leaf damage due to air pollution:
  - (a) Necrosis
  - (b) Chlorosis
  - (c) Abscission
  - (d) Epinasty
3. Explain the various kinds of injury to plants due to air pollutants.
4. Explain the effects of various air pollutants on plants.
5. Explain the effects of the following air pollutants on plants:
  - (a) Sulphur dioxide
  - (b) Ozone
  - (c) Peroxy acetyl nitrate (PAN)
  - (d) Hydrogen fluoride
  - (e) Ethylene
6. Explain the effects of photochemical smog on plants.
7. Explain the importance of genetic and climatic factors in relation to the effects of air pollution on plants.
8. Write a note on: Time-concentration equations.
9. Explain how leaf destruction in relation to the yield can be expressed mathematically.
10. Give the specimen of a typical air pollution injury report.



Wished to stay and is gone  
 How am I theirs  
 If they cannot hold me  
 But I hold them!"

### 1.3 IMPORTANCE OF AIR POLLUTION CONTROL

Of all the problems man is facing today at the dusk of the twentieth century, the most intriguing is Air Pollution.

Man can survive for 5 weeks without food, 5 days without water and less than 5 minutes without air. This is attributed to the fact that he breathes, on an average, 25000 times a day at a rate of 1-2 litres of air per breath. The consumption of air by man conditioned by the circumstances is as follows:

Activity	Consumption of Air	
	m <sup>3</sup> /day	kg/day
1. Resting	10	12
2. Light work	40	50
3. Heavy hardwork	60	75

Compared to the consumption of water of about 2 litres a day (2 kg/day) man consumes about 20,000 times more of air by volume and 25 times more by weight. Thus man requires enormous quantities of air for his survival. In addition, the air he breathes goes into direct contact with the most sensitive organs of the human body - the respiratory tract and the lungs. Thus the quality of air he breathes has a direct bearing on his health and well being. That is the reason why the concentrations of pollutants should be very small in air when compared to the corresponding concentrations in water. A concentration of more than 0.3 ppm i.e. 0.3 mg/l or 3,00,000 µg/m<sup>3</sup>, of lead in water is considered harmful to man but a concentration of 1.5 µg/m<sup>3</sup> of lead in air is deadly harmful. Majority of air pollutants like sulphur dioxide, nitrogen peroxide, ozone, ammonia etc. have a direct effect on man, material and vegetation. The air pollutants can affect the environment on a global scale. Carbon dioxide as a greenhouse gas causes global warming, increases mean sea level, submerges millions of hectares of fertile land and brings famine thus leading eventually to destruction of life on this planet. Sulphur dioxide and nitrogen peroxide can bring acid rains which can completely upset the delicate balance between the various biotic and abiotic components of the biosphere. CFCs, the chlorofluorocarbons can destroy the ozone layer, man's protecting umbrella, and spread incurable diseases among human

## 1.5 DEFINITION OF AIR POLLUTION

Engineers Joint Council of U.S.A. defines air pollution as "the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odour, smoke or vapour in quantities, with characteristics, and of duration such as to be injurious to human, plant or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property".

According to the Bureau of Indian Standards, IS - 4167 (1966) air pollution is "the presence in ambient atmospheres of substances, generally resulting from the activity of man, in sufficient concentration, present for a sufficient time and under circumstances such as to interfere with comfort, health or welfare of persons or with reasonable use or enjoyment of property. According to American Medical Association, air pollution is "the excessive concentration of foreign matter in the air which adversely affects the well-being of the individual or causes damage to property".

Thus, if the concentration of any substance or element in air is more than a certain value, it may affect man and his property, directly or indirectly and may be termed as an air pollutant. According to the definition, the study of air pollution is limited only to outdoors i.e. ambient air. But, unfortunately most of the people spend more than 90 % of their time indoors - in their homes, educational institutions, offices or theatres. Thus fumes in kitchens, smoking in closed office rooms, malodorous emissions in an auditorium etc. are not covered under the definition of air pollution.

## 1.6 DEFINITIONS OF AIR - POLLUTANTS

**AEROSOL :** Finely divided solid or liquid particles of microscopic size suspended and dispersed in a gas or in atmosphere as in the case of dust, mist, fog, haze or smoke. The term is applied to the system of dispersed phase and dispersing medium together, while particles alone are called 'aerosol particles'. They range from 0.1 to 100 microns in size. The typical size ranges in microns are: cement 150 - 10; flyash : 80 - 3; spores : 30- 10; bacteria : 15 - 1 and pollens : 6 - 20  $\mu$ .

**DROPLET:** A small liquid particle of such size and density that it falls under still conditions but may remain suspended under turbulent conditions.

**DUSTS :** They are small solid particles generated by crushing, grinding, blasting, processing or handling of materials such as coal, cement or grains eg. sawing of wood, sand blasting, cement manufacturing . Their size ranges from 1 to 200 microns. They remain in suspension and do not diffuse. Particles of size above 75 microns would come into the category of grit. If

the particle size is less than 0.1 micron, they are affected by Brownian motion. They collide with the surrounding particles, congregate, flocculate and then settle down finally. Most of the dusts settle on ground as dust-fall but particles less than 5  $\mu$  in size become stable substances in the atmosphere.

**FLY ASH:** Non-combustible particles contained in flue gases. They are released when organic portion of coal is burnt. Like dust, its size is 1 to 200 microns; like smoke it results from burning and like fumes it consists of inorganic metallic or mineral substances.

**FOG :** Atmospheric obscuration caused by mists. In meteorological terms, fog implies reduction of visibility to less than 1 km.

**FUMES :** Very fine solid or liquid particles, 0.001 to one micron in diameter. Often, they are metallic oxides like zinc oxide and lead oxide, formed by the condensation of vapours of solid materials. They are formed by sublimation, distillation, calcination or molten metal processes. Like dusts they may flocculate, coalesce and settle out. The word fumes is commonly used to imply unpleasant and smelling airborne effluents.

**GASES :** One of the three states of matter having no independent shape and expanding continuously till its volume equals that of the container.

**MISTS:** Liquid particles formed by condensation of vapour (as in distillation) or dispersion of a liquid (as in foaming or splashing of water) or a chemical reaction (as in the formation of  $H_2SO_4$ ). Usually applied to water droplets in air where visibility has a value of 1 km or more. Natural mists may be aggravated by air pollutants. If their concentration is high and decreases visibility to less than 1 km, it is called fog.

**PARTICLE :** A small discrete mass of solid or liquid matter.

**SMOG :** Term derived from smoke and fog (smoke + fog = smog).

**SMOKE :** Finely divided gas borne aerosol particles of size range 0.001 to 1 micron, resulting from incomplete combustion of fuels. It mainly consists of carbon and other combustible material.

**SOOT :** Small agglomerations of carbonaceous particles impregnated with tar formed by the incomplete combustion of carbonaceous material, particularly bituminous coal. They tend to adhere to the inside of the chimney or the exposed surfaces.

**VAPOUR :** The gaseous phase of matter which normally exists in a liquid or solid state (eg. gasoline, steam)

## 1.7 MEASUREMENT OF AIR POLLUTION

Air pollutants like water pollutants, are expressed in ppm or micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ). For water, 1 ppm = 1 part of pollutant in 1 million parts of water i.e. 1 mg per  $10^6$  mg i.e. 1 mg/l. However, for air it is not so. One gram - mole of any gas at STP conditions occupies the same volume of 22.4 litres. Thus 64 gms. of  $\text{SO}_2$  or 30 gms. of NO or 46 grams of  $\text{NO}_2$  or 48 grams of  $\text{O}_3$ ,.... all these occupy the same volume of 22.4 litres at  $0^\circ\text{C}$  temperature and 760mm of Hg pressure. The volume occupied is 24.5 litres at  $25^\circ\text{C}$  and 760mm Hg. pressure.

∴ If M is the molecular weight of a gas, then, M grams of it occupies  $22.4 \times 10^{-3} \text{ m}^3$  at  $0^\circ\text{C}$  and  $24.5 \times 10^{-3} \text{ m}^3$  at  $25^\circ\text{C}$ .

$$\begin{aligned} 1 \text{ ppm} &= \frac{1 \text{ part of gas}}{10^6 \text{ parts of air}} = \frac{1 \text{ m}^3 \text{ of gas}}{10^6 \text{ m}^3 \text{ of air}} \\ &= \frac{M/(22.4 \times 10^{-3}) \text{ grams}}{10^6 \text{ m}^3} = \frac{M}{22.4} \times 1000 \mu\text{g}/\text{m}^3 \text{ at } 0^\circ\text{C}. \\ &= \frac{M}{24.5} \times 1000 \mu\text{g}/\text{m}^3 \text{ at } 25^\circ\text{C}. \end{aligned}$$

The conversion factor may be written in a general form as follows:

$$1 \text{ ppm} = 44.64 M \times \frac{273}{273 + T} \times \frac{P_2}{P_1} \mu\text{g}/\text{m}^3 \text{ where}$$

M = Molecular weight of the pollutant (gas)

T = Temperature of gas in  $^\circ\text{C}$

$P_1$  = Pressure at STP conditions and  $P_2$  = Pressure of gas (air)

The ppm -  $\mu\text{g}/\text{m}^3$  conversion factor for different gases is given in table.

Pollutant	Molecular Weight, M	ppm - $\mu\text{g}/\text{m}^3$ conversion factor	
		$0^\circ\text{C}, 760 \text{ mm}$	$25^\circ\text{C}, 760 \text{ mm}$
$\text{O}_3$	48	2142	1960
$\text{SO}_2$	64	2860	2620
CO	28	1250	1145
$\text{CO}_2$	44	1964	1796
HC (as $\text{CH}_4$ )	16	715	655
NO	30	1343	1230
$\text{NO}_2$	46	2054	1880
$\text{CH}_3(\text{CO})\text{O}_2$	121	5348	4945
$\text{NO}_2$ (PAN)			

## **CHAPTER - 2**

### **SOURCES OF AIR POLLUTION**

One of the early steps involving air pollution problems is to locate the source from which air contaminants are being emitted. There are more than 7,50,000 man-made chemicals present in our environment and to these 1000-2000 new ones are added every year. Massive production of such chemicals directly or indirectly releases thousands of tonnes of a variety of air pollutants into the atmosphere. Some of the air pollutants emanated into the atmosphere by man are CO, CO<sub>2</sub>, SPM, SO<sub>x</sub>, odours, noise, NH<sub>3</sub>, gases and vapours, dusts of toxic metals like Lead, Arsenic, Asbestos, Nickel, Mercury, Phosphorus and their oxides, Vanadium, Zinc, various hydrocarbons, Fluorides etc. The pollution made by man is vast and the pollutants made by men are plentiful.

#### **2.1 CLASSIFICATION OF AIR POLLUTANTS**

Air pollutants and their sources may be classified as follows :

- Primary and secondary pollutants
- Line and areal sources
- Natural and artificial sources

#### **2.2 PRIMARY AND SECONDARY POLLUTANTS**

Primary pollutants are those which are emitted directly from identifiable

sources. Particulates,  $\text{SO}_2$ , oxides of nitrogen, CO, radio active elements, halogens and organic compounds, fumes, carbon, tar, resins, pollens, bacteria etc. are the different primary pollutants.

Secondary pollutants are those which are formed in the air due to interaction of primary air pollutants among themselves or by reaction with normal atmospheric constituents like sunlight, water vapour etc. with or without photoactivation.

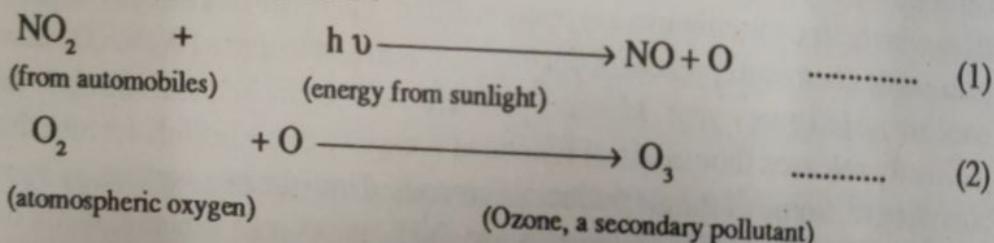
Eg :- Ozone,  $O_3$ ; Formaldehyde,  $CH_2O$ ;

PAN (peroxy acetyl nitrate)  $\text{CH}_3(\text{CO})\text{O}_2\text{NO}_2$ ;

Acidic mists like  $H_2SO_4$  ( $SO_2 + \text{Moisture}$ ); smog; photochemical smog  
**photochemical Smog**

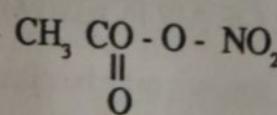
## ~~Photochemical Smog~~

It was first discovered in Los Angeles, U.S.A. in 1940s and now has been detected as a common phenomenon in most of the metropolitan cities of the world including Bombay and Calcutta. The conditions for the formation of photochemical smog are air stagnation, abundant sunlight and high concentrations of hydrocarbons and NO<sub>x</sub> in the atmosphere. Huge quantities of NO<sub>x</sub> and HCs are released due to the massive emission rates of automobiles and some stationary sources. Due to complex photochemical reactions secondary pollutants such as ozone, aldehydes, ketones and PAN are formed. A simple methodology is as follows :



Under normal circumstances this ozone decomposes back to  $O_2$  and the nascent oxygen combines with NO to form  $NO_2$ .

The nascent oxygen reacts mainly with NO<sub>x</sub> to form PAN.



or peroxy formyl nitrate  $\text{HCOOONO}_2$  (PEN)

or peroxy benzyl nitrate  $C_6H_5COONO_2$  (PBzN)

Also, ozone reacts with hydrocarbons to form aldehydes and ketones. CO and SO<sub>2</sub> also play vital roles in the formation of photochemical smog.  
A typical composition of photochemical smog is given below :

Constituent	Concentration in ppm
NOx	20
NH <sub>3</sub>	2
H <sub>2</sub>	50
H <sub>2</sub> O	20,00,000
CO	4,000
CO <sub>2</sub>	40,000
O <sub>3</sub>	50
CH <sub>4</sub>	250
Higher paraffins	25
C <sub>2</sub> H <sub>4</sub>	25
Higher olefins	25
C <sub>2</sub> H <sub>2</sub>	90
C <sub>6</sub> H <sub>6</sub>	10
Aldehydes	60
SO <sub>2</sub>	20

### Effects of Photochemical Smog

- (i) The compounds of formaldehyde, acrolein, PAN and PBzN are highly irritant to eyes.
- (ii) O<sub>3</sub>, NO<sub>2</sub> and PAN present in photochemical smog cause necrosis and silvering or bronzing of the underside of leaves. Vegetation is badly affected by photochemical smog.
- (iii) Carbon, sulphur and halides present in the smog cause visibility problems. The usual size of aerosols present is about 0.3 microns.
- (iv) Ozone present in the photochemical smog badly damages the side walls of automobile tyres, unless anti-ozonants are used. Gaskets, hoses, wire insulations and other miniature electronic circuits are also badly affected.
- (v) The national ambient air quality standard for photochemical oxidants expressed as equivalent to ozone is 240 µg/m<sup>3</sup> (0.12 ppm) averaged over

one hour period. Highly motorized areas like Los-Angeles often experience much higher concentrations causing a severe economic loss.

The photochemical smog can only be controlled by controlling the pollutants responsible for its formation viz. NO<sub>x</sub>, CO, HC, O<sub>3</sub>, etc., for which automobiles are the main sources.

### 2.3 STATIONARY AND MOBILE SOURCES

Stationary and mobile sources of air pollutants are classified as follows.

#### STATIONARY SOURCES

##### Single or point sources

- Industrial process chimneys  
i.e. stacks of steel mills, power plants, oil refineries, pulp and paper industries etc.
- Municipal incinerators

##### Multiple or area sources

- Domestic combustion of fuel in residential areas, offices, apartments, hotels, hospitals and institutions
- On site incinerators
- Evaporation
- Commercial heating
- Open burning

#### MOBILE SOURCES

##### Line sources

Highway vehicles,  
trains, channel vessels

##### Areal sources

air crafts, light, medium and heavy duty vehicles, railyard locomotives, port vessels.

### 2.4 SIGNIFICANCE OF NATURAL AND ARTIFICIAL SOURCES

The different natural and artificial pollutants - their sources and sinks, emission rates, background concentrations etc. are described in detail in the following Table 2.1

Out of the total particulate emissions of about  $2900 \times 10^6$  TPA, about  $2600 \times 10^6$  TPA is from natural sources only, with less than  $300 \times 10^6$  TPA from artificial sources. Similarly, bacterial activity of soil, a natural process, releases about 400 million tonnes/year of NO whereas the total artificial production is less than  $50 \times 10^6$  TPA. Thus the quantities of artificial pollutants released into the atmosphere are very less compared to the quantities of natural pollutants. However large the natural pollutants may be they are evenly distributed over

## **CHAPTER - 3**

### **EFFECTS OF AIR POLLUTANTS**

A normal human being breathes about 25,000 times a day at a rate of about 1-2 litres of air per breath i.e. about 25,000 to 50,000 litres/day i.e. about 30 to 60 kg of air per day. Thus the quantity of air consumed by an average man is about 25 times more by weight and 20,000 times more by volume than the quantity of water consumed. A person can survive for five weeks without food and five days without water but only five minutes without air. In addition, the air we breath interacts with the most sensitive organs of human body. Hence the air we breath must be of a very good quality. Unfortunately man is not equipped with household or portable air cleaning devices unlike water filters etc. and thus demands a clean ambient air for his health and well-being which is more than a luxury today.

Air that surrounds a man has a direct impact on his health and property. The health of a man is determined by the interplay and integration of the internal environment of man himself and the external environment that surrounds him. A disease is only due to a disturbance in the delicate balance between man and his environment. Now-a-days it is not only stacks or chimneys alone where soot is detected as a cause of cancer but carcinogens are found else where also in the environment where very potent cancer causing agents such as benzopyrene and many other polycyclic aromatic hydrocarbons are present in significant concentrations in air. Ofcourse, man is the primary source of air

pollutants. He breathes fresh air and emits polluted air containing pathogens and other aeroallergens, CO, CO<sub>2</sub> and odours. A study by the World Health Organisation shows that 75-90% of all cancers are caused due to environmental factors and are related to agents present in air, water, work environment and personal choice of life style including tobacco smoking and chewing, alcohol consumption and sexual promiscuity. The effects of air pollutants on atmosphere, animals including man, materials and vegetation are thoroughly discussed in this chapter.

### 3.1 EFFECTS OF AIR POLLUTION ON MAN

"Health is a state of complete physical, mental and social well-being and not merely an absence of disease or infirmity" is the widely accepted definition of health. Health is a fundamental human right and is the essence of life and is man's world-wide social goal. The signs of physical health of an individual are a good complexion, a clean skin, bright eyes, lustrous hair, a physique that is good looking - neither too fat nor too lean, neither too tall nor too short, firm flesh, a sweet breath, a good appetite, sound sleep, regular activities of bowels and bladder, smooth, flexible and coordinated bodily movements, normal functioning of different organs, special senses, normal pulse rate and normal blood pressure. Mental health may be defined as a state of balance between the individual and the surrounding world, a state of harmony between oneself and others, a co-existence between the materials of the self and that of their people, and that of the environment. The health of a man is determined by the interplay and integration of the internal environment of man himself and the external environment that surrounds him. A disease is due to disturbance in the delicate balance between man and his environment.

Man's health is easily affected by air pollution. The inhalation of gases and particulates through human respiratory system is a direct form of air pollution. The factors governing the impact of air pollutants on man are (i) the type of pollutants (ii) concentration and duration of the pollutants and (iii) health condition of the recipient.

#### The Human Eye

Even though no lasting damage to the eye has been attributed to air pollution, the sharpness of vision is reduced by excess carbon monoxide. Smog, when present in considerable amount causes irritation to the eye. When gaseous or particulate materials contact the external coat of the eye and the internal mucous lining of the eyelid, the eye will be irritated. However to relieve this irritation, excessive rubbing will be done, which will cause physical damage. Some particulate materials combined with ozone, oxides of nitrogen, aromatic hydrocarbons and synthetic pollutants cause irritation.

## The Respiratory System

It is certain that the respiratory system is affected more than any other part of the human body because the basic functions of the respiratory system are to inhale air into the lungs, filter impurities from the inhaled air, supply oxygen contained in this air to the circulatory system, and exhaling CO<sub>2</sub> from the circulatory system.

The upper respiratory tract removes particulates larger than 10 microns in diameter by inhaling and then immediately exhaling the air. The lower respiratory tract consists of the bronchi, bronchioles, alveolar ducts, alveolar sacs and the alveoli of the lungs. Air is first drawn through the large bronchi and then through a system of branching ducts. Human respiration may be divided into ventilation and respiration.

Pollutants enter the body through the respiratory system, which can be divided into the upper respiratory system, consisting of nasal cavity and the trachea, and the lower respiratory system, consisting of the bronchial types and the lungs. At the entrance to the lungs, the trachea divides into two bronchial trees which consist of a series of branches of successively smaller

diameter. At the end of the bronchioles are large collections of tiny sacs called alveoli. It is across the alveolar membranes that oxygen diffuses from the air in the sacs to the pulmonary capillaries and CO<sub>2</sub> diffuses in the opposite direction.

The respiratory system has several levels of defense against invasion by foreign material. Large particles are filtered from the air stream by hairs in the nasal passage and are trapped by the mucous layer lining the nasal cavity and the trachea.

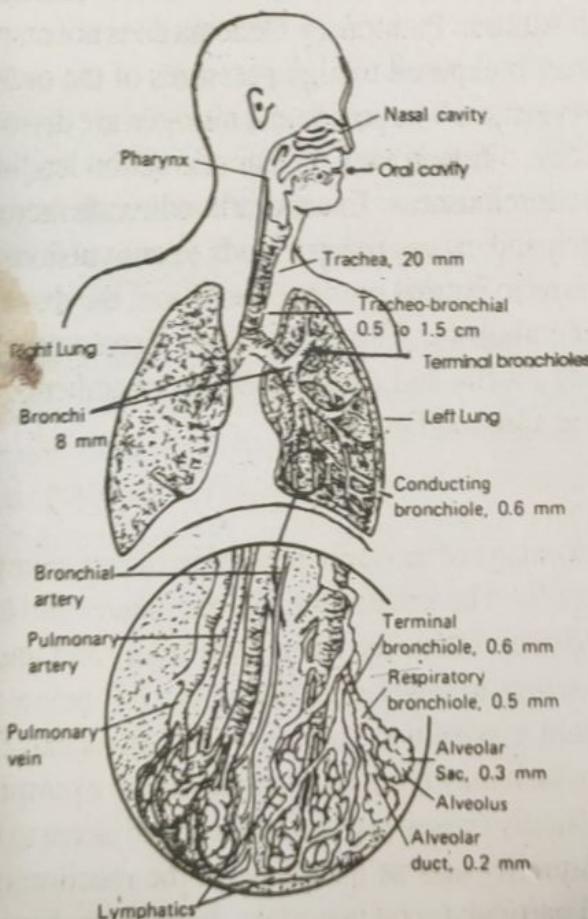


Fig. 3.1 Human Respiratory System

### 3.2 EFFECTS OF NATURAL AIR POLLUTANTS

#### (i) Atmospheric Pressure

Atmospheric pressure decreases with increase in altitude. At an altitude of about 30 km above MSL the pressure is hardly 10 mm of Hg. The pressure increases at the rate of  $1 \text{ kg/cm}^2$  i.e. 760 mm of Hg for each 10m depth under water below sea level. Barometers are the instruments employed for measuring pressure.

A pressure of about  $1\text{kg/cm}^2$  is comfortable for man. Density of air and pressure decrease with altitude. Man cannot survive at an altitude of about 8 km without breathing equipment. This is mainly due to increase in respiration, the concentration of hemoglobin and the increase in cardiac output. Persons at higher altitudes and exposed to lower pressures suffer from headache, insomnia, breathlessness, nausea, vomiting and impaired vision.. This may be due to various intricate biochemical and hormonally disturbances in the body and is popularly known as mountain sickness.

Persons exposed at altitudes of above 4 km. experience irregular breathing, oliguria, mental confusion and hallucinations, stupor, seizures and coma. The condition known as High Altitude Pulmonary Oedema does not respond even to antibiotics. When man is exposed to high pressures of the order of 10 atmospheres, gases like oxygen, carbondioxide and nitrogen are dissolved in the blood and tissues. Excess nitrogen exerts a narcotic action leading to loss of mental functions and consciousness. Excess carbondioxide increases the narcotic action of nitrogen and excess oxygen leads to convulsions and death. When the person returns to normal pressure condition, the dissolved gases are released causing air embolism. This is a common disease observed in persons working in diving wells and compressed air chambers. The disease is popularly known as Caisson Disease.

#### (I) Relative Humidity

Relative humidity is the percentage of moisture present in the air, complete saturation being taken as 100%. The greater the RH the nearer the air to saturation. If RH exceeds 65% air inside the room feels sticky and uncomfortable. Better ventilation serves to lower such humidity. RH below 30% also is unpleasant. Permanent exposure to such low humidities can cause drying of the nasal mucosa which may predispose to infection, exemplified by sore throat and cough. Usually coastal regions and areas adjacent to huge water bodies are humid. Humidity acts as a catalyst in the reaction of air pollutants like  $\text{SO}_2$ ,  $\text{NO}_2$  and particulates on materials. In indoors, humidity increases due to evaporation of moisture from skin and lungs. The exhaled air contains about 6% of moisture.

### (iii) Temperature

Thermal comfort is a complex entity . For a long time, air temperature was used as an index of thermal comfort, but it was realised that air temperature alone was not an adequate index of thermal comfort. Later, air temperature and humidity were considered together to express thermal comfort. A temperature of about 77-88°F i.e. 25 - 27°C is the comfortable range of temperature. The average temperature of earth is about 16°C ranging from 75°C in Turkisthan to minus 90°C in Greenland .

### (iv) Heat (Maximum Allowable Sweat Rate)

4.5 litres of sweat excreted in four hours is considered as the maximum allowable sweat rate compatible with physiological normal reaction in acclimatized, healthy young-men for repeated exposure to heat. Comfort zone may be defined as the range over which majority of adults feel comfortable. There is no unanimous decision on a single zone of comfort for all people because comfort is quite a complex subjective experience which depends not only on physiological factors but also on psychological factors which are difficult to determine.

#### PREDICTED FOUR HOUR SWEAT RATE

1. Comfort Zone	1 - 3 litres
2. Just tolerable	3 - 4.5 litres
3. Intolerable	4.5 litres

The rate at which a man sweats is a good index of the heat stress to which he is subjected. A sweatrate of 4.5 litres in 4 hours is the upper limit of tolerance in health for work in hot environment. A sweat rate of 2.5 litres in 4 hours is considered optimal for a working man. When humans are exposed to heat as many as 14 disorders have been recognised. Some of them are:

**Heat Stroke:** This is attributed to failure of the heat regulating mechanism and is characterised by very high body temperature and profound disturbances including delirium, convulsions and partial or complete loss of consciousness. The skin becomes dry and hot. Death is often sudden and may be due to hyperpotassemia. Hyperpotassemia may be due to the release of potassium from red blood cells which have been injured by heat. The treatment consists in rapidly cooling the body in ice water baths till the temperature falls to below 103°F. The patient should be kept in bed for several days.

**Vanadium:** Vanadium is emanated into the atmosphere by vanadium refining industries, alloy industries, power plants and utilities using vanadium-rich residual oils. Vanadium is moderately toxic to humans, especially in its pentavalent form. Physiological effects of varying severity are on the gastro - intestinal and respiratory tracts and inhibition of cholesterol synthesis. Chronic exposure to vanadium leads to heart disease and cancer.

**Zinc:** Most of the zinc is evolved from zinc refineries, manufacturing of brass and zinc galvanizing processes. Except in high concentrations, zinc and its compounds are generally considered to be non toxic to humans. However, inhalation of zinc oxide fumes produces metal fume which is a non fatal but self-limiting illness. Accidental poisoning can result from ingestion of acidic foods prepared in zinc galvanized containers. Since zinc is commonly associated with other metals in the air, it is difficult to assess its value as a separate air pollutant. Inhaling zinc in air causes emaciation and swelling of limb joints of cattle and horses requiring slaughter.

### 3.4 EFFECTS OF PRIMARY AIR POLLUTANTS

The effects of the main air pollutants namely CO, SO<sub>x</sub>, NO<sub>x</sub>, oxidants, HCs and particulates on man, material and vegetation are described in detail as follows :

**Carbon Monoxide:** The sources of CO are both natural and anthropogenic. Oxidation of methane gas from decaying vegetation, human metabolism and gasoline powered internal combustion engines lead to CO emission.

Carbonmonoxide, at present ambient levels, has little effects on property, vegetation or materials. 'CO', when inhaled, passes through the lungs and diffuses directly into the blood stream where it combines with the red blood pigment called hemoglobin forming carbaoxl hemoglobin, COHb. The affinity of carbon monoxide for hemoglobin is 200 times greater than that of oxygen and as a result the amount of hemoglobin available for carrying oxygen for body tissue is considerably reduced. The body tissues are thus deprived of their oxygen supply. Heart patients may lack sufficient cardiac reserve to compensate. Patients with angina pectoris require less exertion to induce chest pain. Carbonmonoxide concentrations are especially high in congested urban areas where traffic is heavy and slow moving. A person trapped in traffic at such a location for an hour would show a COHb blood level close to 2-3 percent. This exposure would affect the central nervous system, impairing a person's time interval discrimination, brightness discrimination and other psycho-motor functions. The absorption of CO by the human system increases with its concentration, exposure time and the activity being performed.

The chronic effects of CO are not fully known but they may induce heart and respiratory disorders. While CO itself has not been found to be carcinogenic, there is concern that it may increase the carcinogenic effects of other air pollutants by inhibiting the mucociliary clearance mechanism in the lungs. 1-2% of COHb levels have an evident effect on the behavioral performance of the humans. If COHb levels exceed 5%, cardiac and pulmonary functional changes are observed. 10% and more COHb levels may cause headaches, fatigue, drowsiness, coma, respiratory failure and death.

✓ **Oxides of Sulfur:** The burning of fossil fuels contributes more than 80 percent of anthropogenic SO<sub>2</sub> missions. Fuel combustions in stationary sources and industrial processes are the principal contributors of SO<sub>x</sub>. Combination of these oxides with water (H<sub>2</sub>SO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub>) and the salt derived from these acids, when combined with other elements are well-known atmospheric pollutants. Intense irritation and reduction of visibility have also been recorded from epidemiological studies pertaining to sulfur oxides.

Plants are more sensitive to SO<sub>2</sub> during periods of intense light, high relative humidity, adequate moisture and moderate temperature. Excess exposure to SO<sub>2</sub> accelerates corrosion rate of many metals such as iron, steel, zinc, copper and nickel. Sulfuric acid mists can cause damage to cotton, linen, rayon and nylon. Leather also weakens and disintegrates in the presence of excess amounts of products of sulphur. Paper absorbs SO<sub>2</sub> and becomes brittle.

Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), Sulfur dioxide (SO<sub>2</sub>) and sulfate salts tend to irritate the mucous membrane of the respiratory tract and expedites the development of chronic respiratory diseases, particularly bronchitis and pulmonary emphysema.

✓ **Nitrogen Oxides, NOx:** Some oxides of nitrogen are produced naturally. Small concentrations of NOx produced in the upper atmosphere by solar radiation reach the lower atmosphere thorough downward diffusion. Small amounts of NOx are produced by lightning and forest fires. Bacterial decomposition of organic matter also releases NOx into the atmosphere. The implementation of more stringent controls for carbon monoxide and hydrocarbons resulted in the increased emissions of NOx. The greatest significance of NO is related to its tendency to undergo oxidation to NO<sub>2</sub>.

Affinity of hemoglobin for absorbing NO<sub>2</sub> is 3,00,000 times that for O<sub>2</sub>. This affinity drastically reduces the O<sub>2</sub> carrying capacity of the blood. NO is a relatively inert gas and only moderately toxic. NO<sub>2</sub> irritates the alveoli of the lungs. The response of the human respiratory system to long-term exposure to nitrogen dioxide depends upon the concentration of NO<sub>2</sub>. The olfactory

They cause swelling when they enter the lungs. Aromatic hydrocarbons are more dangerous than acyclic and alicyclic hydrocarbons. The inhalation of their vapours cause acute irritation to the mucous membrane. Excess of hydrocarbon increases mucous secretion as a result of which respiratory tracks are blocked and man coughs regularly. Because of continuous cough much pressure is caused on the trachea of lungs due to which the lining membrane of alveoli bursts and very small area is left for exchange of oxygen and carbon dioxide. Benzopyrene, which is present as trace amounts in tobacco, charcoal, boiler stacks and gasoline exhausts etc. is a dangerous cancer inducing hydrocarbon pollutant. Methane also is a severe gas pollutant and occurs in air by volume of 0.0002 percent. Its higher levels in absence of oxygen, create narcotic effects on human beings. A group of hydrocarbons, especially the carcinogenic hydrocarbons, cause cancer in man and animal affecting DNA and cell growth.

TABLE 3.1 : HAZARDS OF CARCINOGENIC HYDROCARBONS:

S.No.	Compound	Health Hazards
1.	Benzene	Bladder cancer
2.	Naphthylamine	Cancer in urinary bladder
3.	Bichloromethyl ether	Lung cancer
4.	Ethylene dichloride	Stomach, spleen and lung cancer
5.	Vinyl chloride	Liver cancer
6.	Ethyleneamine	Cancer
7.	Propiolactone	Potential carcinogen
8.	Naphthylamine	Bladder cancer
9.	Nitrophenol	Bladder cancer
10.	3-3' dichlorobenzidine	Cancer

Hydrocarbons and photochemical oxidants are injurious to plants also. Ethylene, even at 1 ppm concentration, shows adverse effects on vegetation. Acetylene and propylene at 50-500 ppm show extreme toxicity towards plants damaging growth of vegetation. Ethylene hydrocarbons inhibit plant growth, damage leaf tissues and cause death of flowering plants. Hydrocarbon pollutants damage long chains of carbon atoms in materials and reduce the strength of polymers.

**Particulates:** The effect of particulates on human beings depends mainly on their size and characteristics. Size is one of the most important physical parameters of particulates. Particle sizes are measured in micrometers. Particle sizes larger than 50  $\mu\text{m}$  can be seen with unaided eye. Particulates

### 3.5 EFFECTS OF AIR POLLUTION ON ATMOSPHERE

The effects of air pollutants on atmosphere at macroscale are covered in detail in the topic on "Global effects of air pollution". The localized effects of air pollutants on atmosphere are:

1. Visibility reduction
2. Fog formation and precipitation
3. Solar radiation reduction
4. Temperature and wind distribution alteration

Perhaps the most noticeable effect of air pollution on the properties of atmosphere is the reduction in visibility which may lead to safety hazards. The prevailing visibility is defined as the greatest distance at which it is just possible to see and identify a prominent dark object in day time and an unfocussed, moderately intense light source at night. Visibility is reduced by absorption and scattering of light. Visibility is reduced when there is significant scattering. This decreases the contrast between the object and the background sky, thereby reducing visibility. Large particles scatter light by three processes, reflection, diffraction and refraction. Particles of very small size scatter light equally in forward and backward directions. This effect in fact, is responsible for the reddish hue of sunsets, since the shorter wavelength blue component of sunlight is scattered out of the line of sight leaving the red components to reach the observer.

Scattering and absorption of both solar and infrared radiation, occur within the polluted layer. During the day the net effect of pollutants on the temperature of the urban dome depends on the relative magnitude of heating caused by absorption of solar radiation and cooling due to emission of infrared radiation. In addition to reduction in visibility air pollution effects urban climate with respect to increased fog formation and reduced solar radiation.

#### Economic Significance of Visibility Impairment

Reduction in visibility due to air pollution creates an economic burden because of increased requirements for electricity in homes, in business establishments and in the streets when sunlight cannot penetrate the haze. Air port operations are slowed down because of the delays in air traffic, which add to operational costs, inconvenience to passengers and pose additional hazards to safety that may result in death, personal injury or property damage.

Highway traffic is impaired when a motorist's vision is limited. Traffic arteries may be closed to a stand still and accidents causing bodily injury,

death and increased property damage may occur. If the community is near a harbour, ship traffic may suffer in the same way as air and highway traffic. Serious indirect costs may arise if air ports have to be relocated or enlarged to handle slower traffic. Additional highway requirements and increased insurance rates and other indirect economic costs may result from reduction in visibility if it becomes exceedingly severe or frequently occurring.

Scattering of sunlight by particulates suspended in the atmosphere is the main cause of reduction in atmospheric visibility. This condition is comparable to a dirty automobile wind-shield. At night with no on-coming vehicle, it is not too bothersome, however, when strong light from the sun or vehicular light strikes the dirty wind-shield the driver's visibility is impaired. A concentration of  $150 \mu\text{g}$  of 1 micron diameter particles per  $\text{m}^3$  of air borne particulates affects visibility which is dependent primarily on the number of particulates and their size. Submicron sized particles or smaller scatter more light than the large particles, since scattering area per gram of material is greater for smaller particles. Since light scattering is the main cause of reduction in visibility, this aspect of air pollution is manifested primarily during bright days when there is strong light to be scattered by the suspended particulates.

### **Pollutants Contributing to Impairment of Visibility**

Major contributors to impairment of atmospheric visibility are hygroscopic particulates. Some hygroscopic particles, such as soluble organics and sulfur trioxide from industry, are produced by man; others come from natural sources, such as sea salt spray. Opaque agglomerations such as carbon, fur and metal particles in the atmosphere also contribute to reduced visibility. Crystalline compounds such as iron, aluminum, silicon and calcium which may exist as sulfates, nitrates, chlorides and fluorides also contribute to light scattering.

### **3.6 AIR POLLUTION EFFECTS ON VEGETATION**

The most obvious damage caused by air pollutants to vegetation occurs in leaf structure. The surface of leaf is covered by a waxy layer known as cuticle. Between the waxy layers, epidermis is present, which is a single layer of cells forming the surface skin of the leaf. The epidermis will protect the inner tissues from excessive moisture loss and prevent the admission of  $\text{CO}_2$  and oxygen to these internal tissues. The leaf surface has a large number of openings called the stomata. Gaurd cells will protect the stomata and also control the opening and closing of stomata. A typical plant cell has three components-the cell wall, the protoplasm and the nonliving inclusions within the cell. Because the cell wall is extremely thin during the formative stage, new growth is very much susceptible to air pollution damage. The

consequences of air pollution. On December 4, 1952 a high temperature air mass created a temperature inversion as a result of which a white fog blanketed London from 5th December to 8th December. About 4000 persons already suffering from bronchitis and other respiratory problems died. Particulates and  $\text{SO}_2$  levels rose due to the extensive use of coal fired heating and power production systems. It should be noted that the coal used in great Britain has a sulphur content of 1.5 percent and that the coal was burnt in inefficient open grates. The subsidence inversion did not allow the pollutants to disperse as a result of which the fog became so black that a white shirt became almost black within 20 minutes. There was no movement of air and the visibility was practically zero on these days. It is said that one could not see one's hand in front of one's face. The smog was intensely irritating to the human respiratory system and the people soon developed red eyes, burning throat and nagging coughs. Again on 6 January, 1956 extra deaths in London were blamed on an extended fog and the parliament passed the Clean Air Act in 1956.

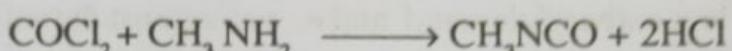
**Poza Rica, Mexico:** On November 24, 1950, Poza Rica, a town of 15,000 people on gulf of Mexico, was struck by a disaster. This disaster was originated from an accident at one of the local factories which recovers sulphur from natural gas. The release of hydrogen sulfide into the ambient air lasted for only 25 minutes. The gas under a shallow inversion with foggy and calm condition crept into the nearby houses and killed 22 people and hospitalized 320.

### Bhopal Gas Tragedy

Modern technological developments have multiplied the hazards to which human beings are exposed. Nearly 5 million chemicals have been synthesized in the world during the last 40 years and some 50,000 to 70,000 chemicals are used extensively in millions of different commercial products without the availability of proper toxicological information on the majority of chemicals.

On the fateful night of 2-12-1984 and in the early hours of 3-12-1984 more than one million residents of Bhopal, the capital of Madhya Pradesh of India reported irritation of eyes that quickly became unbearable, followed by the macabre death dancing in their dear houses. (A cloud of poisonous gas was released from the union carbide plant. The plant was a pesticide manufacturing unit) owned by Union Carbide India Limited, a subsidiary of Union Carbide, a leading company based in the USA. (The factory was licensed to produce methyl iso cyanite,  $\text{CH}_3\text{NCO}$ , an extremely hazardous chemical, which is used in the manufacture of several pesticides like Sevin Carbaryl and

Temik 10-G. MIC is also used by various organic industries as an intermediate. (Carbonmonoxide, CO obtained by partial oxidation of coal is combined with chlorine gas in the presence of activated carbon to form phosgene,  $\text{COCl}_2$ . Phosgene and methyl amene combine to form methyl iso cyanate.) The product is stored in tanks for further use to produce carbomite insecticide.



The carbide plant had three storage tanks for MIC, each capable of holding 45 tonnes. (The union carbide manual on standard operating procedure warns that if water leaks into the system it results in the evolution of a lot of gas and liberation of heat . This is precisely that what happened.)

**Possible Reason for the Tragedy:** On December 2, 1984 the supervisor on duty, who was new to the MIC unit asked an operator to wash the inside of a length of piping near the reactor. It was a standard procedure to insert a metal sheet called a slip blind near a valve to seal off the rest of the system from the tube being washed. The probable and possible reason for this tragedy is suspected to lie in this . Sources believe that the slip blind was not inserted when the operator connected the water hose pipes to the tubes required to be washed.

Shortly before the change in the night shift that Sunday, the count down to the Bhopal disaster started. (At about 11 P.M. one of the operators noticed that pressure in a MIC storage tank read 10 pounds per square inch four times the normal and soon after a lot of workers noticed that their eyes began watering and stinging. The MIC drip at about 15 meters off the ground was accompanied by yellowish white gas. Sooner the leak had grown much larger and the entire area of MIC tanks was enveloped in the choking fumes.) The concrete slab above one of the MIC tanks (of around 5" thick) was found shaking by the workers. (The pressure has gone above 55 psi, which opened the safety valve and MIC vapour could be seen escaping from an atmosphere vent line 35m in the air. Bhopal tragedy, like other air pollution disasters was associated with a thick winter fog and thermal inversion which did not allow the pollutants to disperse and dilute.)

Some observers had alleged that two other gases, hydrogen cyanide and phosgene were also present in the gas cloud (It was alleged that MIC is stored upto a purity of 99.5% and that 0.1 % of phosgene is permitted as an impurity. If 40 tonnes of MIC vaporized that night, as much as 40 kg of phosgene also could have vapourised.) However, the presence of phosgene was denied by Union Carbide.

**About the Toxicity of MIC:** (MIC is a toxic gas which even in low concentrations causes lung, eye and skin irritation and larger doses would remove oxygen from lungs and thus cause death due to anoxia. MIC is just lighter than water and twice as heavy than air and hence moves at lower levels only. MIC can react with any chemical including itself, to evolve considerable heat and CO<sub>2</sub>. MIC in the storage tank was stored for more than 2 months because of less carbaryl demand and it was against the safety rules.)

**Unusual Death Trap:** (On the ill fated 1984 December 2nd night the public woke up coughing and vomiting, with their eyes burning uncontrollably. Of Bhopal's one million population more than 5,00,000 fled on roads to nearby towns and hospitals. The roads were full of crowds and foul smelling due to vomitings. (At about 3 A.M. the gas spread over to 40 sq.km. and seriously affected the people at a distance of 5 to 8 km.) 'It was like breathing fire', said one supervisor.

In Hamida hospital the first patient with eye irritation was reported at 1.15 A.M. and by 2.30 A.M. there were 5000 patients. Thousands waited for medical care inside the hospitals and screams and sobs filled the air. Dead bodies were found lying all over the streets and in the corridors of hospitals with their bodies bloated and blood stinking over the floors. The manager of the three local cremation grounds said that 7000 more bodies were cremated in 1985 than in 1984 including 1,017 children in Hindu cremation grounds. Bhopal victims support committee claims that the death toll could have reached 15,000. Approximately 2,00,000 people had adverse health effects resulting from the disaster, ranging from the temporary blindness and burning lungs to permanent disability. Of 2500 women who were pregnant at the time more than 500 had mis-carriages and about 100 had still births. By 3 A.M. the safety valves reseated themselves as the tank pressure dropped below 40 psi. The public siren was resumed at around 3.30 A.M. but by that time there was no need for caution.

Many of the people died where they were. When the gas reached the railway station, the supervisors diverted the incoming trains. The diversion cut off a possible means of escape but may have saved hundred of lives. The whole station was quickly enveloped in gas. The deputy chief power controller, who alerted all the nearby stations to stop trains from coming into Bhopal died alongwith the station master. Cattle and animals were found lying dead on the roads.

(A medical survey held about three months after the disaster revealed that out of 2,50,000 people exposed 70,000 were severely hit from eye, respiratory, gastro intestinal, neuromuscular and gynecological disorders) About 50,000

people were subjected to moderate medical treatment. (Doctors predicted an increased risk of sterility, kidney and liver infections, tuberculosis, vision problems and brain damage.)

The MIC unit was allowed to work without any preventive devices. On the ill fated night the vent scrubber, that neutralises the gas with caustic soda failed in its duty of detoxicating the escaping gas. The flare tower which is supposed to burn the escaping gas was without the pilot flame because the concerned pipe got corroded. It is unbelievable to know that the 30 tonne refrigeration system which is a must to keep MIC storage tanks at 15°C was out of condition, even though the boiling point of MIC is 39°C only, and flash point is 7°C. Even the water curtain which can be used to cool the escaping gas could not reach more than 15 meters high, though the safety valve outlet is at a much greater height. To the ill fated people of Bhopal every thing would have been right if not for the improper maintenance of the safety systems. For the people of Bhopal it was an ill fated Sunday night. Today many people work with dark glasses and with shrouds to protect their injured eyes and body. Everywhere there were remainders of the disaster. It is the unanswerable questions that will continue to haunt its population for generations to come, as survivors tell their children about the tragedy that rocked Bhopal. Bhopal holds out lessons that have to do with basic concerns, for safety, for standards and for good sense. If the lessons are not needed then it is possible that accidents such as this may be repeated in another factory in another city in another way leading to much more severe tragedies.

### **The Chernobyl Nuclear Disaster**

April 27, 1986 was a sad day in the history of nuclear power generation as a major accident occurred at an atomic reactor at Chernobyl in the Ukraine area of the erstwhile Soviet Union. This had resulted in clouds of radioactive smoke over a large area in scandinavian countries about 2000 km away, and in the Russian region itself.

The first explosion at reactor number 4 at the Chernobyl complex occurred on April 26, 1986 and resulted in a massive and uncontrollable fire. The explosion on April 26 was followed by a second explosion on May 5th. Majority of the radiation was released in the 10 day period between April 26 and May 5, 1986. After May 5th the fire was brought under control and a sharp drop in release of radiation was observed. But small amounts of radionuclides were released for several weeks even after the fire was controlled. The explosion and fire was caused by failure of emergency cooling system in the light water graphite reactor, due to human error. The explosion and subsequent hot fire (about 2500°C) blew large amounts of radionuclides high into the atmosphere. About 10.19 Bq of radio nuclides

## **CHAPTER - 4**

### **GLOBAL EFFECTS OF AIR POLLUTION**

Tropospheric and stratospheric ozone depletion, aerosol scattering and absorption of solar and terrestrial radiation, green-house gas warming, rain and precipitation quality, long-range transport of air-pollutants, heat-islands and urban air quality are known to be the main global air pollution problems. Man at the end of the 20th century has at last realized that the complexities of pollutant interaction with the atmosphere are not confined to a local scale. In the name of 'Pollution Control by Dilution' millions of tonnes of a variety of toxic air pollutants are released into the atmosphere by man which are transported to places several thousands of kilometers away from the source through atmospheric circulation systems causing irreparable damage to the quality of air on continental and global scales . The impacts of air pollution on biosphere and the quality of life have drawn considerable public attention, and air pollution problems are being considered and tackled on a global scale. The word 'global' need not necessarily mean that the pollutant under consideration encompasses the entire globe and are not unique to individual locations. The environment in which we live is unfortunately the host medium for air pollutants also. Man is the sole culprit in polluting the air and he alone should take the responsibility to clean the atmosphere and protect the environment. The various global effects of air pollution are discussed in this chapter.

#### 4.1 GREEN HOUSE EFFECT

Solar energy in the form of light radiation has wavelengths in the range of 0.2 to  $4\mu\text{m}$ . It will lose some energy after striking the earth and will be converted to heat energy of longer wavelengths. Thus the wavelength of this terrestrial reradiation, from earth to atmosphere is more ( $4-100\mu\text{m}$ ) ( $E=h\nu=hc/\lambda$ ). After striking earth since energy decrease,  $\lambda$ , the wavelength increases). Carbon dioxide has radiation absorption bands in the range of  $12-18\mu\text{m}$  wavelengths. Thus if  $\text{CO}_2$  is present in the atmosphere, it allows the incoming solar radiation to pass through but does not allow the reradiation from earth to space to pass through. This is the origin of the term 'Green House Effect' since the glass in a green house also is transparent to short wavelength solar radiation and absorbs the long wave length radiation, emitted from inside the green-house.  $\text{CO}_2$ , water vapour, methane,  $\text{N}_2\text{O}$ , ozone and CFCs cause similar effects and hence are called green house gases. As these green house gas molecules absorb energy, their temperature increases and they themselves start radiating heat. Only a part of it escapes out into the space while the remaining is radiated back to earth further increasing its temperature. Green House Effect, GHE is essential for mankind and life. But man's activities are accelerating or enhancing the warming process to cause concern.

#### Sources of Green House Gases

The various sources and sinks of green house gases are presented in Table 4.1

The main source of GHE is carbondioxide. About 50% of GHE may be attributed to  $\text{CO}_2$ . The 1983 estimate gives a value of  $5.6 \times 10^{12}\text{kg}$  of carbon, apportioned as follows globally.

North America	:	26.7 %
USSR	:	17.6 %
East Europe	:	15.6 %
West Europe	:	6.5 %
Asia	:	18.5 %
Japan	:	5.8 %
Others	:	9.3 %

Presently more than 10,000 million tonnes of carbon dioxide is released into the atmosphere every year due to the combustion of fossil fuels with about 25% of it from industries. USA alone produces about 2500 million tonnes of  $\text{CO}_2$  per year. The  $\text{CO}_2$  concentration in

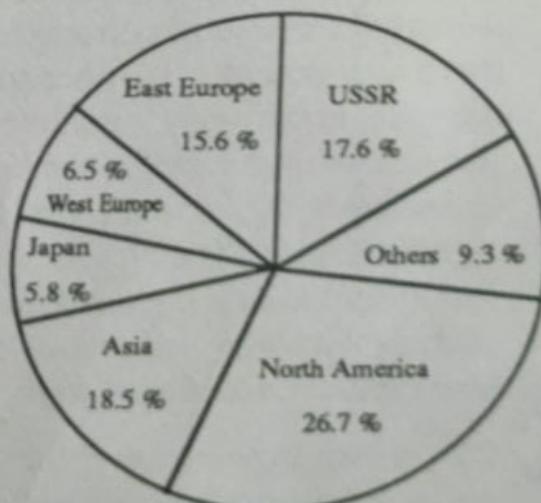


Fig : 4.1 Global Contribution  
of Green House Gases

the pre-industrial era was 265-290 ppm and today it is about 340 ppm. This change is mainly due to the combustion of fossil fuels of coal, petroleum etc. by industries. For example, modern thermal power plants release about 50 million tonnes of CO<sub>2</sub> per year into the atmosphere. The annual coal consumptions by NTPC of India alone are 10,8.7, 5.6 and 5.2 million tonnes at Singrauli, Ramagundam, Korba and Farakka respectively.

Water vapour is another green house gas that absorbs IR radiation below 8 μm (and < 20 μm) while CO<sub>2</sub> has absorption bands in the region of 12 to 18 μm. It has a residence time of about 10 days which is very low compared to that of other green house gases.

### Impact of Green House Effect on Environment

1. Global warming-a global warning : Due to the specific characteristics of the green house gases, the radiation from earth cannot reach the space above as a result of which more and more heat is radiated back to earth. Due to this, the mean ambient air temperature is expected to increase at an alarming rate of about 0.5 to 1 °C per decade. However, an increase in temperature will increase evaporation which may lead to more clouds, more cooling and less ambient temperature. Hence a logistic model considering different parameters must be developed while estimating the degree of global warming. The period from 1967 to 1986 showed an increase of 0.36°C in the northern hemisphere and 0.23°C in the southern hemisphere.
2. According to World Health Organisation, mosquitoes may have longer lives and breed in larger numbers due to global warming and hence may spread malaria. Warmer and humid conditions may also enhance the growth of bacteria and moulds and their toxic products resulting in increased amounts of contaminated and spoilt food. According to WHO, there is a potential for increased air pollution related morbidity and mortality in the world population due to the release of green house gases. Increase in mean global temperature in association with depletion of ozone layer may increase the incidence of 'non melanoma skin cancers' by even 35% by 2060. It will be much more in the southern regions where ozone depletion is high. It also forecasts an increase in natural disasters such as cyclones and floods and short-term but dramatic changes in temperatures, like heat waves.
3. CO<sub>2</sub> is also expected to influence intensely the process of depletion of ozone layer which would further make the climate hot.
4. Global warming may increase Mean Sea Level significantly. The factors influencing the phenomena of rise in Mean Sea Level are thermal

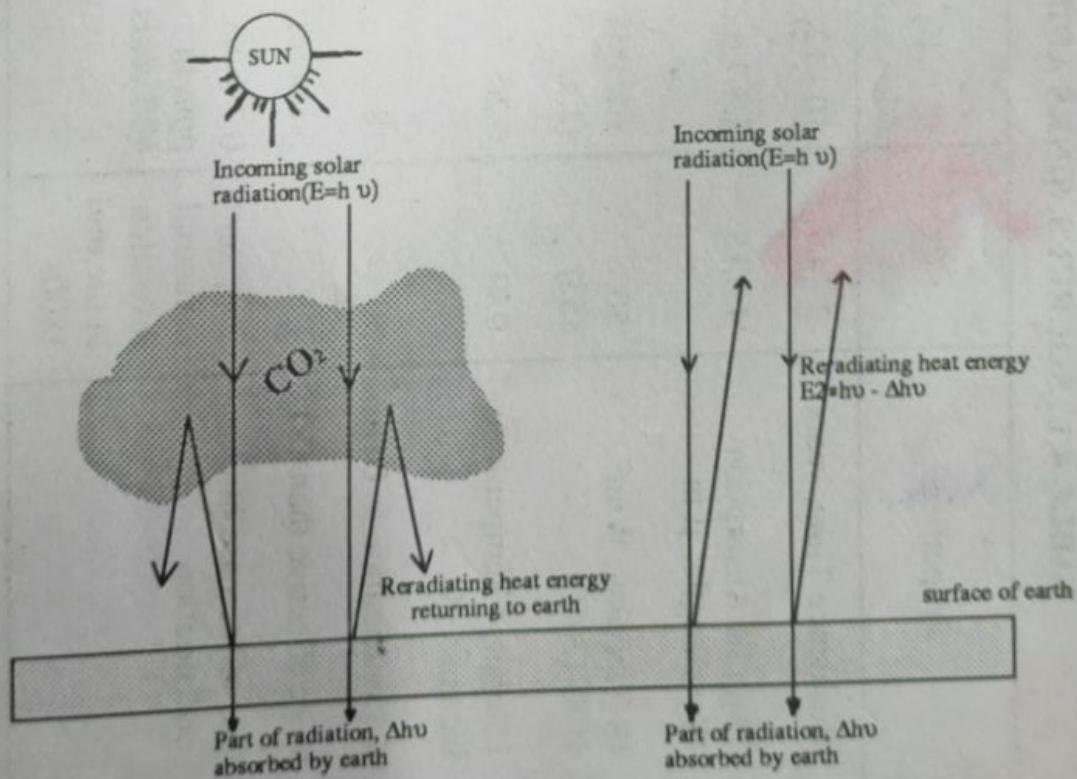
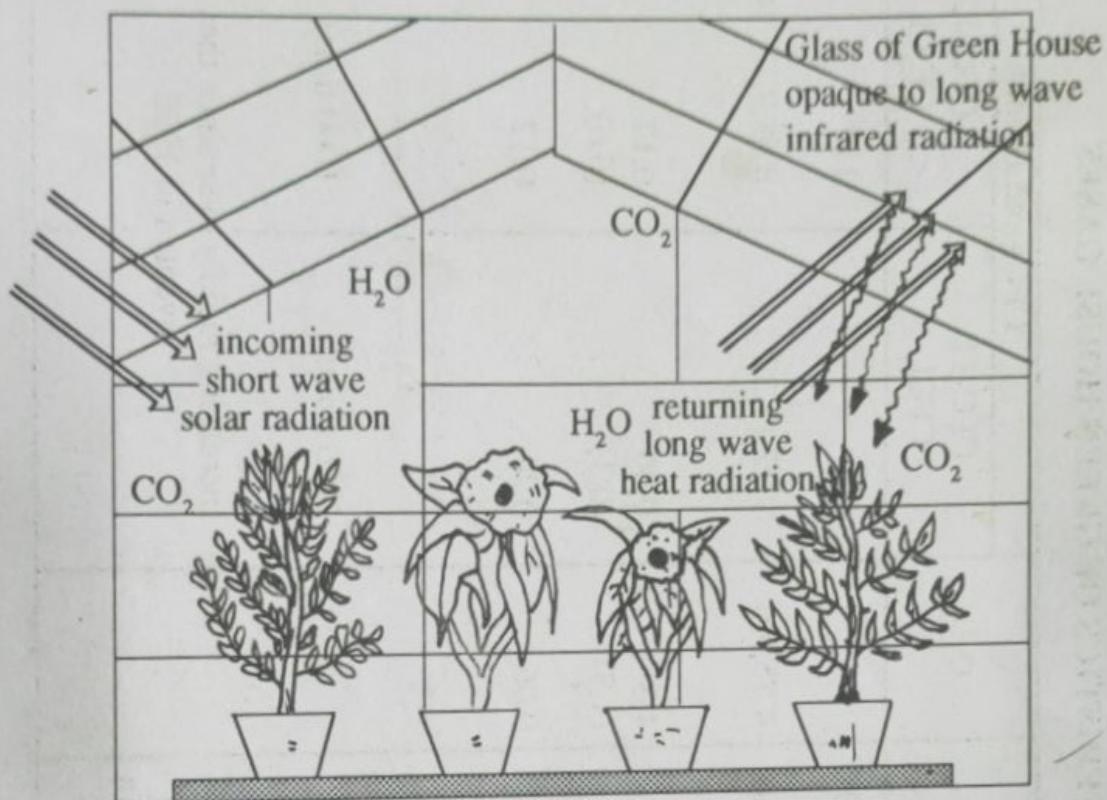


Fig.4.1 Green House Effect

expansion of water (especially the top 1000 m of ocean surface), changes in run off due to changes in precipitation and changes in evaporation into a warmer atmosphere. However, the main factor is the melting of ice caps and glaciers. About 10% earth is covered by glaciers. Out of the total amount of water (other than water in oceans) present in the environment, nearly 75% of water ( $29,000 \times 10^{12} \text{ m}^3$  out of  $38,000 \times 10^{12} \text{ m}^3$ ) is present in ice caps and glaciers at the Himalayas, Arctic and Antarctic regions. Thus the increase in ambient air temperature will increase the mean sea level. The following data indicates the water present in various sources.

Total water sources	$1360,000 \times 10^{12} \text{ m}^3$	100%
Oceans	$1320,000 \times 10^{12} \text{ m}^3$	97.3%
Atmospheric water vapour	$13 \times 10^{12} \text{ m}^3$	0.001%
Surface waters	$230 \times 10^{12} \text{ m}^3$	0.017%
Ground water + soil moisture	$8417 \times 10^{12} \text{ m}^3$	0.615%
Ice caps and glaciers (at Arctic and Antarctic regions)	$29,200 \times 10^{12} \text{ m}^3$	2.14%

The level of Caspian Sea has already increased by 1 meter as per recent reports. Sea level has been raising for centuries now and it has risen by about 15-20 cms during the last century. It is estimated that the MSL will increase by 0.2 - 1.5 m by 2030 and 0.5 to 3.0 m by 2100 A.D. It is to be noted that a 1-m rise could affect an area of about 5000 lakhs of hectares of land surface much of it being densely populated now and that hundreds of millions of people live in these areas. Displacement of these people may lead to food shortages and famine. For some regions, the problem is going to be severe as relocation is not possible for countries like Indonesia and for some non-human habitats, exemplified by the Everglades National Park of Florida. 90% of Maldives and 80% of Bangladesh would be submerged. In addition, salt water intrusion into coastal wetlands would occur and ground water sources may become more saline.

- With the increased  $\text{CO}_2$  levels, the oceans would be required to absorb and decompose more  $\text{CO}_2$  which can raise their normal level of acidity. It would decrease the biological productivity of the marine ecosystems, thereby changing the whole oceanic climate. However, according to atmosphere feed back mechanism,  $\text{CO}_2$  is released from oceans as solubility of  $\text{CO}_2$  decreases with temperature. Due to this  $\text{CO}_2$  concentration increases with a further corresponding rise in temperature.

6. Increasing concentrations of CO<sub>2</sub> may increase the atmospheric pressure. It would broaden the absorption bands and will increase the opacity of the atmosphere to the outgoing long wave terrestrial radiation. It may increase to such an extent that the whole biosphere may come to a grinding halt.
7. Global warming may also increase precipitation by 4 to 15% and may be characterised by late spring, winter rain down by 10-20% and early autumn rain up by 20-50%. It may also increase the frequency and intensity of tropical cyclones by 20-50%. Wind speeds may decrease by 20% N 36°S and increase to south.

Thus GHE may bring changes in mean sea level , energy supply and demand; water resource availability and its political consequences; agriculture; ecosystems and a variety of economic, social and political circles.

### **Control of Green House Effect**

For the preservation and protection of man and environment, the emission of green house gases must be controlled. Following are some of the methods of control of green house gases.

1. In the natural "Carbon Cycle", CO<sub>2</sub> is removed by two sinks (Sink is a place or mechanism associated with the removal of a pollutant. For example, precipitations remove particulates, soil absorbs carbon monoxide and oceans absorb CO<sub>2</sub>) - oceans and vegetation . The emission rates of CO<sub>2</sub> are more than the absorption capacities of the sinks. Nearly 30 million tonnes of CO<sub>2</sub> is released into the atmosphere everyday due to the burning of fossil fuels. Situation is worse as CO<sub>2</sub> emissions have increased exponentially and at the same time deforestation due to cutting of vegetation and reduction of soil organic matter due to fuel extraction are also at a rapid rate. In 1910, India had 40% forests and it is only 20% today. Due to increase in population deforestation is a rate of 50,000 km<sup>2</sup> per year. Every minute about 40 hectares of forests are destroyed worldwide. So, the only practical solution to the burning problem of global warming is social forestry i.e. community based forest schemes. For example, in China, forests increased from 5% in 1950 to 13% in 1980.
2. As 50% of green house gases are from energy production, the solution to control global warming is to adopt alternate energy sources like tidal power stations, wind power plants, solar power systems etc. Supply of non-conventional energy at subsidized prices may atleast to some extent decrease the emission of green house gases.

3. Majority of the beaches are situated on mild bed slopes. For example, the east coast of India is on a slope of about 400 m in 100 km whereas near Madras it is 40 m in 100 km i.e. 1 in 2500. If the bed slope at a place is 1 in 2000, it means that a 1m raise in Mean Sea Level would make the sea encroach into about 2000m of coastal area (Construction of dikes to protect lands from submerging also can be tried. In Holland, dikes of 10 m above mean high tide have been constructed to avoid the effects of increased M.S.L., but in 1953 severe storms with surges 5m above normal tide overwhelmed the existing dikes and nearly 2000 people died. Subsequently the dikes were raised by 3m!).
4. Water logging from fields, especially rice fields, releases methane, another greenhouse gas. Water logging is a common phenomenon that occurs due to construction of dams for hydro power plants. Hence water logging should be avoided.
5. As a green house gas, one mole of CFC is more than 100 times more powerful than one mole of  $\text{CO}_2$ . The already emanated CFCs will persist in the atmosphere for many decades and continue to contribute GHE because of their long life-spans and high absorbing power for IR radiation. Hence the use of CFCs should be banned all over the world.

### **History of Green House Effect**

About 20,000 years ago the  $\text{CO}_2$  concentration was about 200 ppm only, as a result of which earth's temperature was 4 to 5°K lower than now. It reached a value of 280 ppm about 10,000 years ago, 290 in 1860, about 320 ppm in 1970 , 340-360 ppm in 1988 and is expected to be doubled by 2030 A.D. The changing concentrations of  $\text{CO}_2$  measured carefully at Maunaloa Hawaii, situated away from the industrial populations, indicated a net annual increase of  $\text{CO}_2$  by 0.77 ppm. The role of  $\text{CO}_2$  can be visualised by comparing Earth with Moon and Venus. Venus has a larger  $\text{CO}_2$  content while Mars has very little. The net result is Venus is hot at 477°C, Mars is cold at - 47°C and the earth has an average temperature of about 16°C. The term Green House Effect was first coined by J. Fourier in 1827. The effect is also called as atmospheric effect or global warming.

Several years ago Dr. Gilbert Plass observed that the heat content in rooms with ordinary walls was much lower than the heat content of rooms with glass walls. This is attributed to the property of glass which allows the incoming short wave solar radiation to pass through and becomes opaque for the outgoing reradiated long wave infrared radiation. As mostly glass is used for the walls of green houses meant for plants, this effect of heat retention in a green house is called green house effect. This phenomenon can well be

understood when one returns to the car with closed windows after a while. The glass windows of the car would allow the incoming solar radiation and does not allow it to return, as a result of which more and more heat would be retained inside the car, on a warm day. The incoming UV-visible solar radiation exhibits maximum intensity around 413 nm while energy emitted from earth's surface lies in the infrared region of 2000 to 40,000 nm with a maximum intensity of 10,000 nm. The temperature of earth would have been - 20 to - 40°C if there were no green house gases present.

The CO<sub>2</sub> concentration increased from 265-290 ppm in the pre-industrial era to about 340 ppm in 1988. Similarly, N<sub>2</sub>O concentrations in the pre-industrial era was 0.2 ppm. By 2035 it is expected to be 0.4 ppm. A doubling of its concentration will be equivalent to 0.3°C increase in temperature. Similarly, CFC concentrations are increasing rapidly ever since they were first manufactured in 1930. They have long life spans and are more powerful IR radiation absorbers. During 1860-1985, the cumulative heating rate from all gases was 1.9 W/m<sup>2</sup> as compared to the expected 3.5 W/m<sup>2</sup> for the period 1985-2035.

As early as the 1860s, some observers suggested that slight changes in the composition of the atmosphere might result in major changes in the earth's climate. In 1896, the Swedish scientist Svante Arrhenius had calculated that a doubling of CO<sub>2</sub> in the atmosphere would lead to a global warming of 7 to 11°F (4 to 6°C) which is remarkably close to today's predictions. Roger Revelle, Hans Suess and David Keeling established the first CO<sub>2</sub> monitoring station at Maunaloa, Hawaii and it was observed that the CO<sub>2</sub> concentration increased from 315 ppm in 1958 to 360 ppm in 1987.

The discovery of a hole in the stratospheric ozone layer over Antarctica prompted the signing of the Montreal Protocol on substances that deplete ozone layer, on 16th September, 1987. This protocol mandates significant decrease in CFCs and other hydro carbons that contribute to GHE and hence this is going to control the GHE to a great extent.

According to a recent report by Inter Governmental Panel on Climate Changes (IPCC) there will be a 1°C rise in temperature by 2025 and 3°C rise by 2100. According to UNEP, a 2°C rise in temperature is sufficient to disrupt the earth's heat budget and will cause catastrophic changes in the environment.

**1993 was the second warmest ever after 1994!**

#### **4.2 EFFECT OF PARTICULATES ON EARTH-ATMOSPHERE HEAT BALANCE**

Millions of tonnes of particulate matter is being put into the air by man and

nature every day. These particulates, dusts, fumes, aerosols (0.1 to 5  $\mu\text{m}$ ) etc., will scatter and absorb both solar and terrestrial radiation thereby affecting the heat balance of the globe. Aerosols could reduce the incoming radiation by 10% through back scattering and their increase could probably lead to the cooling of atmosphere. In addition, particulates, especially the dusts, play a vital role in the formation of clouds as they act as nuclei for the condensation of water vapour. The massive injection of particulates from automobiles and industries also increases the reflectivity of atmosphere besides controlling precipitation. Also the rate of increase of atmospheric turbidity has been observed to be greater than that of  $\text{CO}_2$  concentration. Consequently, skies become more cloudy and atmospheric turbidity increases. Hence penetration of solar radiation will be less. Thus the various effects due to the discharge of particulates into the atmosphere could be on earth's reflectivity, its surface temperature, cloud formation and precipitation, earth-atmosphere heat balance and the evaporation-condensation cycle.

#### 4.3 HEAT ISLANDS

The heat energy release causes a significant climate change in cities and may result in global climate effects. Because of the thermal capacitance of the streets, buildings and industries for solar input and because of energy dissipation, cities are warmer than their rural surroundings.

Energy release in urban areas may occur both through evaporation of water, particularly in generation of electric power and in the direct heat of air. As a result, the cities are warmer, rainier and fogger than their suburban surroundings. In highly urbanised and industrialized areas, a difference in temperature of  $6^\circ\text{C}$  is quite common. In such areas, the artificial production of energy approaches nearly 1000 watts/ $\text{m}^2$  while the solar absorption by the atmosphere averages out to be only 25 watts/ $\text{m}^2$ . Thus the city becomes a Heat Island. The city surfaces, due to this effect may be as much as  $10^\circ\text{C}$  hotter than their rural surroundings, when wind is calm. Compared to their rural surroundings, urban areas are typically  $2.5^\circ\text{C}$  warmer; 10% less humid; the wind movement is 25% less; solar radiation is 25% less; precipitation is 10% greater; clouds are 10% more and frequency of fog is 100% greater. Further, the concentration of green house gases just above the urban area may further increase the heat content of the area. Thus the heat islands play their role in increasing the mean global temperatures. This growing thermal burden would inevitably disrupt the climatological and ecological balances.

#### 4.4 ACID RAINS

Thermal power plants, industries and other sources release thousands of tonnes of oxides of nitrogen and sulphur into the atmosphere everyday.

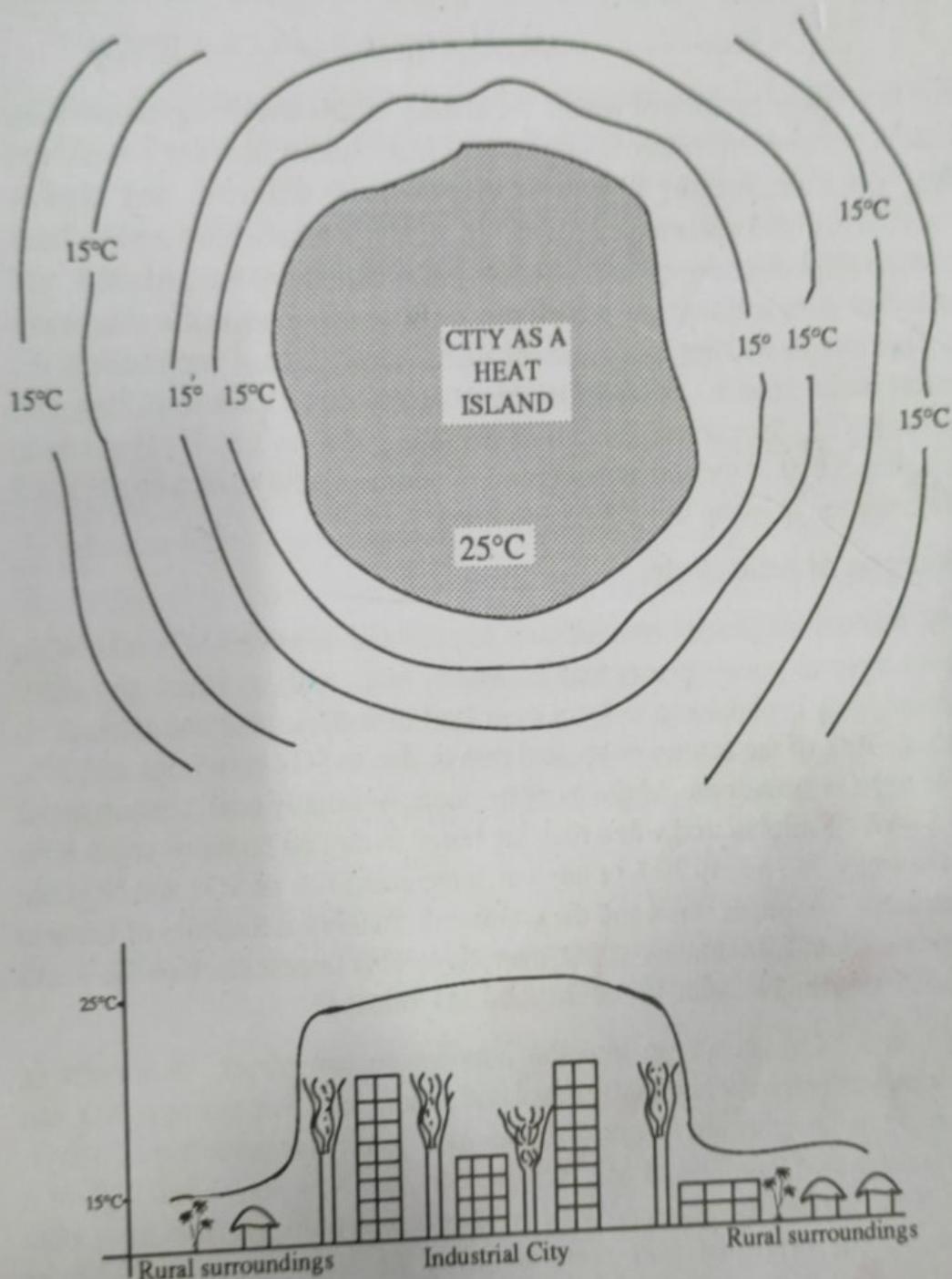
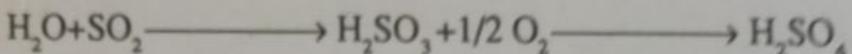


Fig. 4.3 Heat Island Effect

These gases undergo transformation in the atmosphere and form nitrates, sulfates, nitric acid or sulfuric acid droplets. Some of these pollutants, especially the oxides of sulphur can travel 200-300 kms in a day. Thus, the compounds emitted at a place may be carried hundreds of kilometers by the wind and deposited on ground or on vegetation directly as 'ACID RAINS'.



Rain is the purest source of water. 'Acid Rain' means any precipitation- rain, snow or dew, which is more acidic than normal. Acidity of water is measured on a pH-scale, ranging from 0-14 pH. Neutral solutions and freshly prepared distilled water have a pH of 7.0. Acidic solutions have a pH < 7 and alkaline solutions have pH > 7. Lemon juice (citric acid) has a pH of 3. pH scale being logarithmic, an acid of pH 3 is 10 times more acidic than water of pH 5 and 10,000 times more acidic than neutral water. Though rain is the purest water source, it absorbs the atmospheric CO<sub>2</sub> while falling and forms H<sub>2</sub>CO<sub>3</sub>, the carbonic acid with pH falling to even 5.6. If pH of rain is less than 5.6, it is termed as 'acid rain'. Nowadays, acid rains with pH < 4.5 are common in many developed countries.

### Sources of Acid Rain

The massive emissions of oxides of sulphur and nitrogen-SO<sub>x</sub> and NO<sub>x</sub>, from thermal power plants and industries react with moisture and other atmospheric constituents to form a cocktail of sulfuric acid and nitric acid. About 70% of the acidity of an acid rain is due to SO<sub>x</sub> emissions and 30% due to NO<sub>x</sub> emissions. Majority of the fuels, especially coal, contain about 0.5 - 4% of sulphur and when they are burnt in air that contains about 80% of nitrogen and nearly 20% of oxygen, huge quantities of SO<sub>x</sub> and NO<sub>x</sub> are released. The super stack and the mammoth smelters at Sudbury of Ontario release about 2500 tonnes of SO<sub>2</sub> everyday. This largest stack of the world alone contributes about 1% of the total SO<sub>2</sub> released.

SO<sub>2</sub> and NO<sub>x</sub>, swept up into the atmosphere can travel thousands of kilometers before being finally deposited as acid rain. For example, SO<sub>2</sub> can remain in the atmosphere upto 40 hours while a sulphate particle for 20 days. It is estimated that 87% of SO<sub>4</sub> in New York and New Jersey and 92% of it in New England has been carried in by long distant transport from the middle west. The origin of acid rains affecting the lakes, rocks and soils of Adirondack in New York is the industrial sector of the Midwest. Here, the rocks are mainly granites and gneisses which have no buffering capacity and hence the acid rains falling on these Adirondack slopes have greater levels of acidity than the rain itself.

### Effects of Acid Rain

'Acid Rain' is dangerous to man, material and vegetation and can disturb the ecological balance on a global scale. The effects may be summarised as follows:

1. Green algae and many forms of bacteria, which are essential to aquatic life / system are killed due to acidity.
2. High acidity results in the reproductive failure, reduced growth and in the killing of fish. Change in pH prevents hatching of fish eggs and destruction of trout and salmon. Brook trout is the most acid tolerant while rainbow trout the least.
3. At low pH, decomposition of organic matter is less and hence results in the accumulation of organic matter in the water bodies like lakes and streams and hence increases the degree of water pollution. Self purification capacity of water body decreases.
4. Acidity increases the concentrations of heavy metals such as lead, cadmium, copper, zinc, aluminum, chromium and manganese in water. These are highly toxic and hence badly affect the quality of water.
5. Acidity affects germination of seeds. Growth of trees also is adversely affected which results in vanishing of greenery and destruction of forests.
6. Acidity also affects soil by decreasing its fertility. Plant nutrients like potassium are leached out of the soil whereas toxic elements like zinc accumulate. Beneficial microorganisms are killed or reduced. Earth worms, known as 'Farmer's Friends' cannot survive in acidic environment.
7. Acid Rains corrode buildings, monuments, statues, bridges, fences, railings and art treasures. It is an irreparable loss to mankind.
8. In 1958, the Rain falling over Europe had a pH of 5.0. It was 4.5 in 1962 in Netherlands and Sweden. In 1970, ecological damage was observed while in 1979, it was observed that 20,000 lakes of Sweden alone were suffering from loss of flora and fauna. In USA, in 1979, the average pH value of rain was 4.2. In Los Angeles, a pH of 3.0 was noticed for a dense fog. Wheeling (West Virginia) of USA and Pitlochry of Scotland recorded pH of about 2.2 which is more acidic than lemon juice (citric acid) and was as acidic as battery acid. The rain on April 10, 1984 at Pitlochry was nearly one lakh times more acidic than normal water. In India, Bombay and other western parts have experienced acid rains. Taj Mahal, one of the wonders of the world is badly affected by SO<sub>x</sub> emissions from Mathura refinery and elsewhere and the damage is named as 'Stone Cancer' or 'Stone Leprosy'.

Acid rains have already caused severe damage to the environment. About 500 lakes of USA, Canada and Sweden are 'dead' and about 10,000 lakes are fishless. If the occurrence of acid rains continue, it is estimated that by 2000 AD, 50,000 lakes of Canada may perish. Similarly, 30% of West Germany's forests are dying.

### Control of Acid Rains

The only remedial measure to control acid rains is to control the emissions of the oxides of sulphur and nitrogen from industries and power plants, by using proper control equipments and stringent legislations. Periodic application of lime to neutralize acidity is a solution but is expensive and cannot be applied on a large scale.

### Black Snow

During the Gulf war of 1991, thousands of tonnes of smoke and dust were released due to the burning of hundreds of oil wells. A portion of these pollutants carried by wind were finally deposited on the shining skin of the Himalayas as a 'Black Snow'. Hundreds of acres of the Himalayas were covered by a black carpet of smoke and soot. This would not only damage the beauty of the Himalayas but also would lead to higher melting of snow due to the higher absorption of solar radiation by the black surface. The Himalayas are the extremely important components of India and is the main mountain system of Asia, the flora and fauna of which may greatly be affected even when exposed to very low concentrations of air pollutants.

### 4.5 OZONE HOLES

Earth has a protective umbrella in the form of Ozone Layer, of 24km thickness in the stratosphere about 15 km away from earth's surface. The concentration of ozone in this stratospheric ozone layer is about 10ppm compared to 0.05ppm (about 0.0000017%) in the troposphere. Higher ozone concentrations in the troposphere are highly injurious to man and vegetation on earth whereas the stratospheric ozone layer is essential for life to sustain on earth. The ozone layer absorbs the dangerous ultraviolet radiation (especially the UV-B rays with wavelengths from 200 to 280nm) from the sun and converts it to heat and chemical energy. It is this activity that is responsible for the rise in temperature. This layer is not of uniform thickness. Its profile is shaped like that of earth, being highest at equator and lowest at the poles.

In nature, ozone is continuously formed and destroyed through photochemical interaction and an equilibrium in ozone concentrations is ensured. However, this equilibrium is upset due to the discharge of anthropogenic air

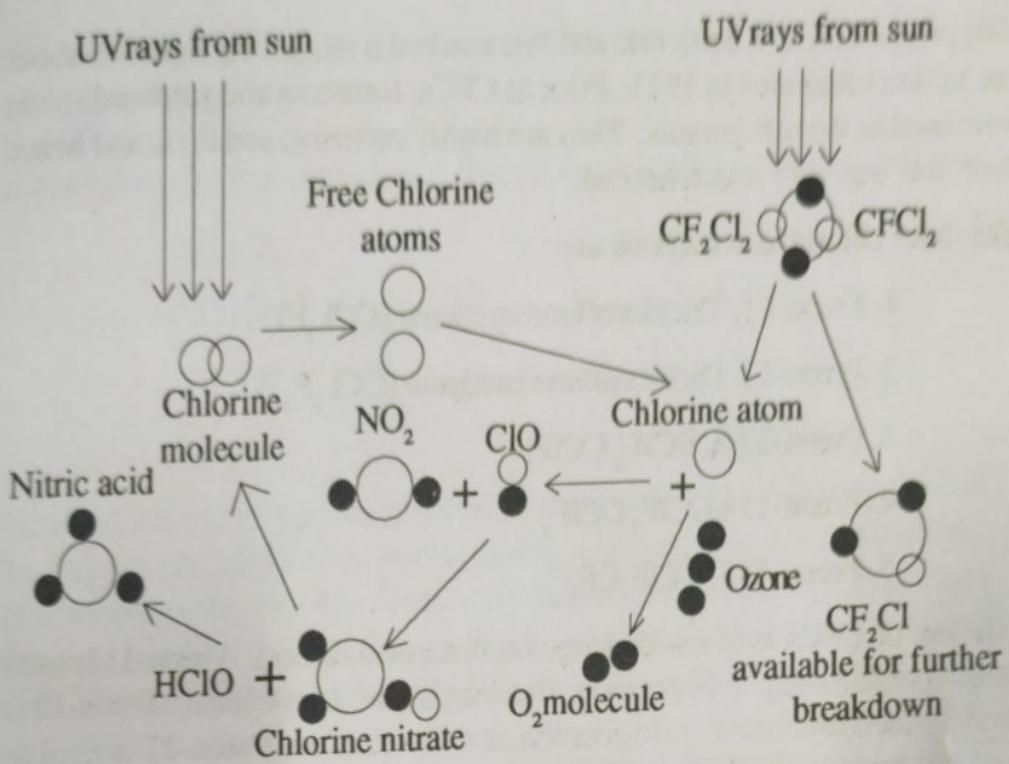


Fig.4.4 Process of Ozone Depletion

pollutants such as CFCs, the chlorofluorocarbons, into the atmosphere. The CFCs release free radicals of chlorine, fluorine or bromine which destroy the stratospheric ozone as a result of which the ozone layer is thinned. The patches of thinned ozone layer are known as "Ozone Holes". By definition the 'ozone hole' represents only a depletion of ozone concentration but not an empty space in the atmosphere. CFCs are the main pollutants responsible for ozone depletion. Their sources and photochemical activity are as follows:

### Sources of CFCs

CFCs (chlorofluorocarbons) are a group of synthetic chemicals developed in 1930 by Dr. Thomas Midgley. Since the conception of Freon-12 in 1930, the use of new refrigerants has increased rapidly. These miraculous refrigerants could be traced as the origin of CFCs. The compound  $\text{CCl}_2\text{F}_2$  is marketed under brand names such as "Freon" and "Genetron". More than three fourth of the world's production of CFCs can be attributed to the United States. The low toxicity, non-inflammability and least chemical reactivity of CFCs made them very popular in being used as refrigerants. CFCs are also used as propellants for dispersing aerosols. In 1940 'DU Point' developed a series of chlorofluorocarbons. The easy handling of CFCs made them popular in almost every field as aero-propellants, cleaning solvent, plastic foams, in fast food packaging, in dry cleaning industries, for sterilizing surgical instruments, in medicinal and oral inhalation products and for cleaning and degreasing electronic equipments. Thus, the demand of CFCs increased

their production at a hefty rate and this reached a staggering figure of about one billion kilograms in 1973. Prior to CFCs, ammonia and sulphur dioxide were used as the refrigerants. They are highly corrosive and toxic and hence their use was very much limited.

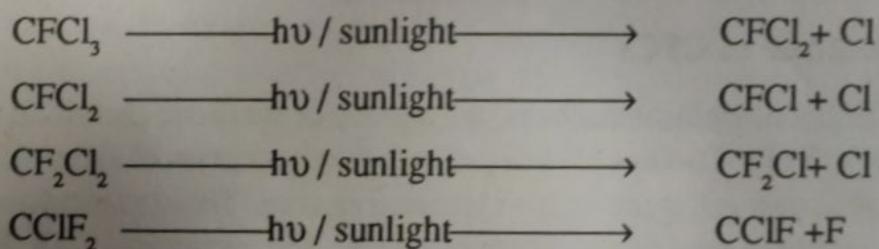
The chief chlorofluorocarbons are:

1. Freon-11, Trichlorofluoromethane ( $\text{CCl}_3\text{F}$ )
2. Freon-12, Dichlorofluoromethane ( $\text{CCl}_2\text{F}_2$ )
3. Freon-22,  $\text{CHClF}_2$
4. Freon-114,  $\text{CClF}_2\text{CClF}_2$
5. Freon-115,  $\text{CClF}_2\text{CF}_3$

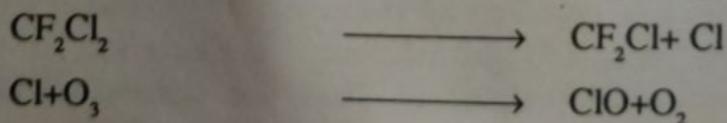
The use of CFCs is of a wide range (as discussed earlier). Freon-11 is used in air conditioning, refrigeration, cleaning foams, aerosols etc. Freon-12 is widely used in aerosols, refrigeration, and sterilization. Freon-22 is used as aerosol-propellants. Freon-113 is mainly used in refrigeration. Freon-114 is used in aerosols, refrigeration, cleaning foams etc. Halons like  $\text{CF}_2\text{BrCl}$  are used in fire extinguishers.

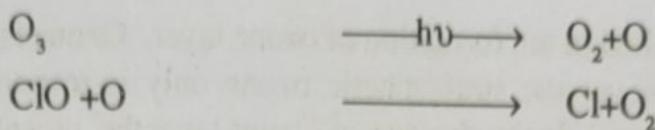
### Photochemistry of Ozone Depletion

CFCs and halons are highly stable. However, the UV radiation between 1750 and 2200 Å present in the stratosphere decomposes them. The chlorine, fluorine or bromine molecules of CFCs and halons are converted into their reactive free radical form by photochemical reactions, as follows:

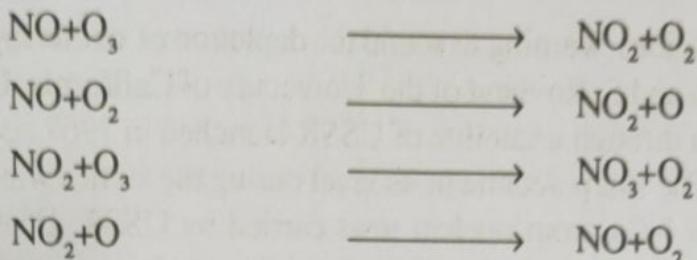


These free F or Cl radicals are released during the reaction in the 'ozone-sphere'. Chlorine is also ejected into the atmosphere by volcanic eruptions and a fraction of it reaches the ozonosphere. Oxides of nitrogen generally inactivate chlorine but the lowering stratosphere temperature changes NO<sub>x</sub> into non-reactive nitric acid. Thus Cl or F are free to react with ozone, disintegrating it into O<sub>2</sub>+O. Each atom of chlorine can destroy more than 1,00,000 molecules of ozone catalytically, converting O<sub>3</sub> to O<sub>2</sub>.





This is more efficient catalytically. The NOx cycle also give the same result.



The above chain reaction takes about 40 years before the full effect is felt. The tiny ice particles during winter favour the conversion of chlorine into chlorinemonoxide, which behaves as a catalytic compound. The total ozone decreases by about 6.5% during the chain, although natural concentration of ozone is maintained by balancing of  $\text{O}_3$ - forming and  $\text{O}_3$ - destroying reactions. But, due to man - made materials, the abundance of chlorine monoxide-rich air in stratosphere continues to rise. This chlorine monoxides reacts with nascent oxygen and free chlorine is formed. Thus the cycle continues destroying the ozone level.

Recently it has been realised that unchecked, uncontrolled use of CFCs can spell an ecological disaster for the world in not too distant a future. Unlike other chemicals, CFCs cannot be removed from the atmosphere by the usual scavenging processes like photodissociation, rainfall, oxidation etc. Recently National Aeronautics and Space Administration (NASA) scientists concluded that CFCs and Halons are the real culprits in depleting ozone layer.

If this ozone layer is depleted, UV rays can travel through the ozone holes easily. Gaseous pollutants such as oxides of nitrogen and CFCs produced due to human activities are capable of bringing about reactions which cause the decomposition of ozone in the upper atmosphere. Supersonic jets and jumbo jets flying in the troposphere exhaust smoke that floats like thin clouds in the air. The CFCs in such clouds react with sunlight to form smog. This raises the temperature of the atmosphere and also causes the thinning of ozone layer.

### **History of Ozone Layer**

When earth was born about 5000 million years ago, there was no ozone layer and UV rays used to reach earth directly. As life is not possible in the presence of strong UV radiations, life in biosphere was limited only to waters 5 to 10m deep where the dangerous UV radiation was cut off and only visible light could penetrate. Yeasts were known to be the first living organisms. Gradually, the photochemical reactions involving different gases in the

atmosphere resulted in the formation of ozone layer. Ozone is present at all altitudes. However the stratospheric ozone only is responsible for the filtration of UV rays. In the absence of Ozone layer the biosphere may turn into a 'blast furnace'.

The first conscious warning to sound the depletion of ozone layer was made by M. Molina and S. Rovland of the University of California, USA in 1974-75. The data through a satellite of USSR launched in 1967 confirmed their prediction. The sharp decline in its level during the sixties was attributed to the release of NO<sub>x</sub> from nuclear tests carried by USSR, USA and France during that time. A gradual stabilization of ozone layer was observed later which may be attributed to the fact that nuclear tests in air were banned later. In 1971, P.J. Curtzen of USA concluded that NO<sub>x</sub> released from supersonic transport fleet could reduce stratospheric ozone by 40%.

The British Antarctic Survey Team (BAST) led by Joseph Farman reported 40% loss of ozone layer during spring over Antarctica in 1985. Further research revealed that the ozone level was dropped by 50% from 15th August, 1987 to 7th October, 1987 and that ozone dropped by 100% in some parts literally forming 'ozone holes'.

The World Watch Institute, USA released the first authentic and well documented picture on 'Ozone Holes' in 1988. The first real measurement of an increase in UV radiation due to ozone holes was reported in 1991 by the geophysicists of Chicago University.

Ozone destruction is a function of several parameters. Greatest reductions would occur at distances of above 40km where the atmosphere is photo-chemically active. Ozone destructions also depend on the geographical locations. For example, the approximate ozone reductions are 4% in tropics, 9% in the temperate zones and 14% in the polar regions. The appreciable decrease in rainfall level in the British Island and the increasing draughts in the world indicate that ozone depletion and global warming have taken place in a slow but sure way.

### **Effects of Ozone Holes**

1. The impacts of a depleted ozone layer on humans depend mainly on their reaction to UV-B rays. It is expected that every 1% loss in ozone leads to 2% increase in diseases. The most significant effect on human beings would be an increase in various skin cancers like melanoma which is malignant and can cause death. Two other types of skin cancers that are increasing are basal and squamous-cell carcinomas. These two cancers do not normally kill humans but may cause disfigurement.

2. It may also increase the incidence of cataracts and photokeratitis as UV rays are easily absorbed by the lens and the cornea of eye.
3. UV-B radiations may damage the cell DNA and thus the genetic structure of humans, animals and other organisms and vegetation.
4. Langerhans cells in the epidermis which produce melanin, that plays a key role in the human immune system, are destroyed by the UV rays. As fair-complexioned skin people cannot produce enough melanin, they are easily affected by skin diseases. For them sunbathing may not be a pleasure any more. Exposure to UV-rays is usually associated with burning sensation and skin aging.
5. UV- radiations make the blood vessels carry more blood making the skin hot, swollen or red and cause sun burns .
6. UV-radiation causes leukemia and breast cancers, although the reasons are obscure.
7. Many micro-phytoplankton are highly sensitive to UV-rays and hence may die. This would affect the productivity of zoo planktons, fishes and other marine animals and hence the whole aquatic system.
8. Crop yields, especially tea, cabbage and soybean will be reduced. The various effects on vegetation are reduction in leaf size, poor seed quality, increased susceptibility to weeds and diseases. Plant proteins are excellent absorbers of UV-rays and hence are susceptible to injury associated with chlorophyll reduction and mutation. UV rays may also lead to greater evaporation of surface waters through the stomata of vegetation and hence may decrease the soil-moisture content.
9. Ozone depletion changes the spectral composition of solar electromagnetic radiation. The increased solar UV-radiation activates the green house effect affecting the global energy and radiation balance. Formation of hydrogen peroxide,  $H_2O_2$  increases due to which acidity of rain or precipitation increases.
10. It was observed that the UV-B radiations may damage even the inanimate materials.

The ozone layer , if not protected, would enormously affect the productivity and stability of eco-systems and the overall environmental equilibrium.

### **Control of Ozone Depletion**

1. More than 80% of ozone depletion may be attributed to the large scale

release of CFCs into the atmosphere. Hence CFCs must first be controlled. There are lot of efforts on earth to decrease the use of CFCs. The 'Montreal Protocol' was a major development in the prevention of the seemingly imminent disaster. There is severe amount of research for alternative technology and substitute chemicals. New techniques have been developed to decrease the leakage of these gases. In Japan success is in the vicinity in finding the alternatives for chlorofluorocarbons. Japanese companies- Mitsubishi Electric and Taiyo Senyo have claimed to have jointly developed an alternative of CFCs. Recently U.S. has developed Bioact FC-7, a successful alternative for Freon-12. Recently U.S. scientists have also discovered bacteria that can eat the main chemicals threatening the ozone layer.

2. The Satellite Research Institute of Frankfort, Germany has developed a method to use hydrogen as a propellant in aerosol sprays which is environmentally friendly and is a safe alternative to CFCs / butane.

After the Montreal Protocol, 'Ozone Treats' was held at London in 1990 and it was decided to totally phase out CFCs and halons by 2000 AD. As majority of Ozone Depletion Substances (ODS) are contributed by the developed countries, they should take the responsibility in mitigating this menace. For example, in India, the per capita consumption of CFCs was 8.8 grams in 1990 and at the most may reach 25 g by 2000 AD whereas the montreal protocol limit was 300gram. The developed countries which are the main contributors of ODS should provide funds for research and development of alternatives to CFCs that are safer, cheaper and have zero ODP (Ozone Depletion Potential). However successful the above research may be, if we want to survive we need to protect the ozone layer by containing ourselves from using CFCs.



## **CHAPTER - 5**

### **METEOROLOGY AND PLUME DISPERSION**

Meteorology means the study of earth's atmosphere. A close relationship exists between air pollution and certain atmospheric conditions like heat, temperature, wind speed and its direction, humidity and precipitation, and it is essential for an environmental engineer to have a thorough understanding of meteorology. Pollutants emanated by various sources into the atmosphere are transported and dispersed by meteorological and topographical conditions. The air borne cycle is initiated with emission of pollutants followed by their transport, diffusion or concentration in the atmosphere and completed by deposition on soil, vegetation, live stock, water surfaces and other objects and these pollutants are finally washed out of the atmosphere by rain or precipitation. In some cases the pollutants may be reinserted into the atmosphere by wind. Many air pollution episodes involved topographical and meteorological conditions that restricted dispersion of air pollutants, causing them to accumulate at harmful levels. In highly urbanised and industrialized areas the pollutants may hasten the deterioration of the buildings and adversely affect men, material and vegetation. Majority of secondary air pollutants like smog are formed due to the interaction of the primary pollutants with the atmospheric constituents. The results of such transformations may not

This  $dT/dZ$  is the rate at which the temperature changes with elevation in a dry adiabatic plume and is called 'Dry Adiabatic Lapse Rate, DALR'.

$$\therefore \text{Dry Adiabatic Lapse Rate, DALR} = -0.4/1.4 \times 29.3 \text{ m/}^{\circ}\text{K}$$

$$= -0.01^{\circ}\text{K/m} = -0.01^{\circ}\text{C/m}$$

However in the environment surrounding the plume the lapse rate may be different. This lapse rate is known as 'Environmental Lapse Rate, ELR', which may vary from time to time, and from place to place as shown in figure 5.3.

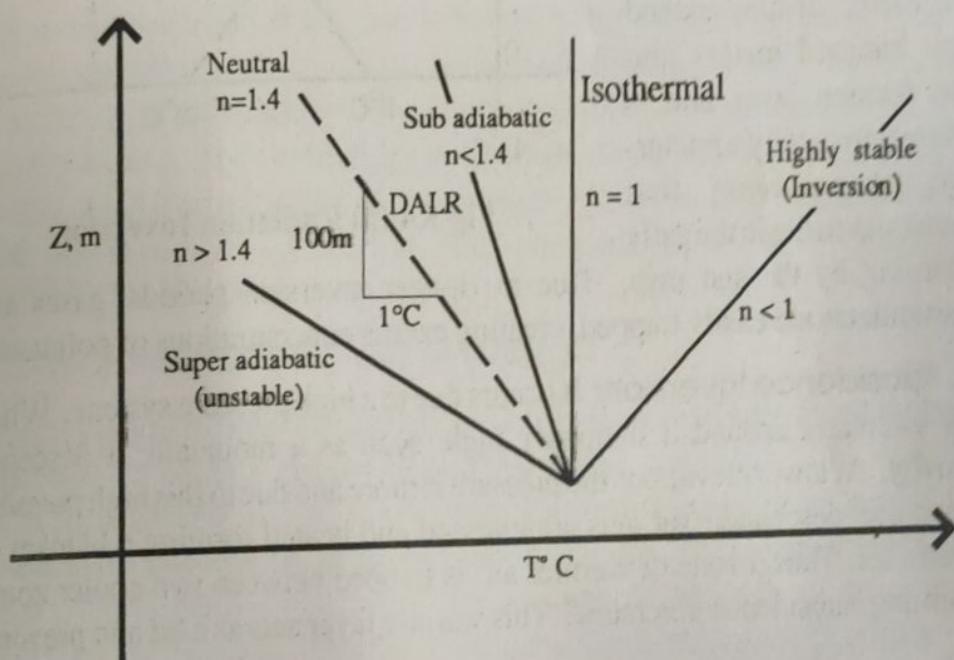
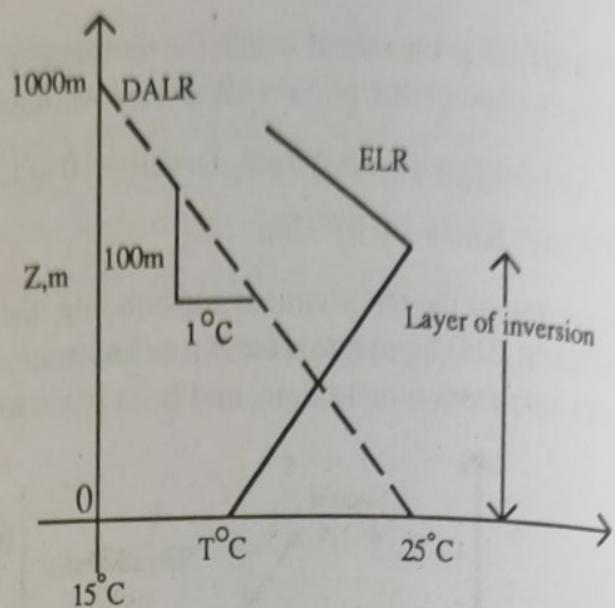


Fig. 5.3 Different Types of Environmental Lapse Rates

**Inversion:** The rate at which temperature changes with elevation is called lapse rate and is given by  $dT/dZ = -(n-1)/nR$ . The lapse rate in a dry and adiabatic atmosphere is called DALR and is equal to  $-1^{\circ}\text{C}/100 \text{ m}$  and such atmosphere is called neutral atmosphere. If  $dT/dZ$  is negative it is called inversion. Inversion occurs when  $n < 1$  i.e.  $dT/dZ$  is +ve i.e. when the temperature of atmosphere increases with elevation instead of decreasing. There are different types of inversions as shown in figures 5.4(a), (b) and (c).

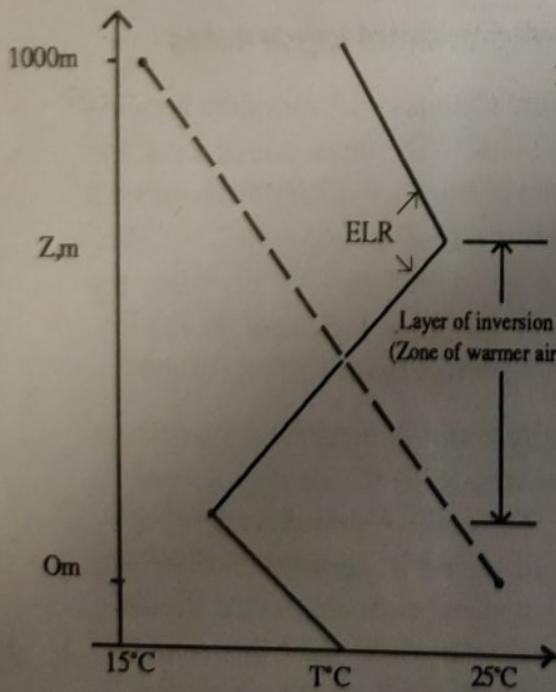
**1. Radiation Inversion:** It occurs usually at night when the earth loses heat by radiation and cools the air in contact with it. If the air is moist and its temperature is very less, fog will form. The cool air stratum is covered by warmer air and the vertical movement of plume is stopped until the sun warms the lower air, next morning. This type of inversion, called RADIATION INVERSION, is common during winter because of the longer nights. Valleys are prone to such radiation inversions due to the restriction of horizontal air movement by surrounding high ground. Due to the simulta-

neous occurrence of fog and high concentrations of mists, such inversions are prolonged as sun rays cannot reach the earth easily. Thus radiation inversion is a phenomenon arising from the unequal cooling rates of earth and the air above the earth. It may extend few hundred meters into the friction layer and is characteristically a nocturnal phenomenon that breaks up easily in the early morning by the sun rays. Due to longer inversion periods, gases and particulates are easily trapped, creating excess concentrations of pollutants.

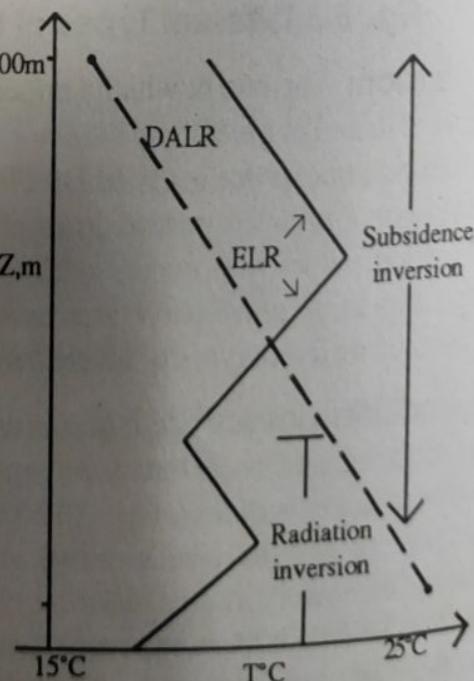


**Fig 5.4 (a) Radiation Inversion**

**2. Subsidence Inversion:** It occurs due to a high pressure system. When air circulates around a stationary high, such as a mountain, it descends slowly. At lower elevations the pressure is more and due to this high pressure zone the descended air gets compressed and heated forming a blanket of warm air. Thus a zone of warmer air is trapped between two cooler zones forming 'subsidence inversion'. This warmer layer acts as a lid and prevents



**Fig 5.4 (b) Subsidence Inversion**



**Fig.5.4(c) Double Inversion**

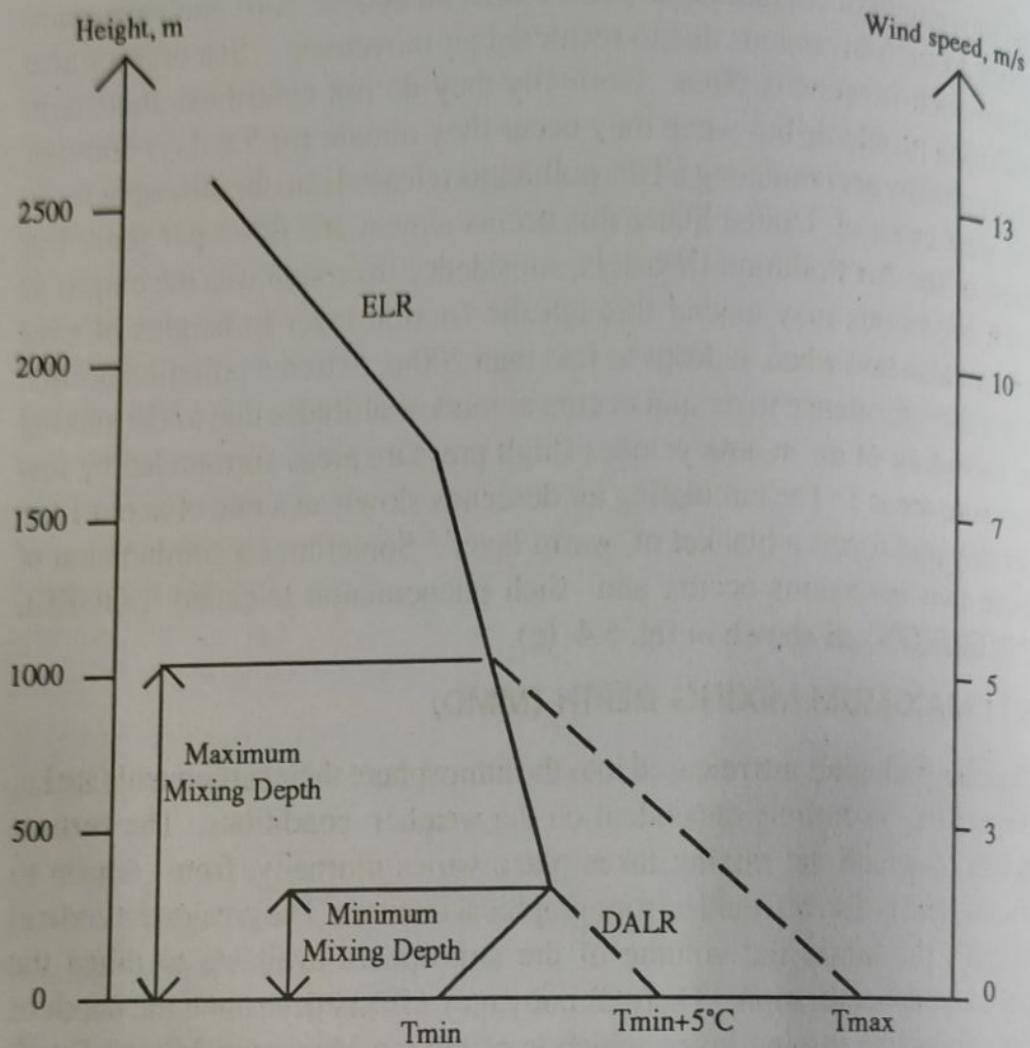
the movement of contaminants to the cooler air above. Hills and valleys are prone to such inversions due to restricted air movement. Sea breezes also cause such inversions often. Normally they do not contribute short-term pollution problems but when they occur they remain for 5,6 days continuously, thusby accumulating all the pollutants released into the atmosphere. In the west coast of United States this occurs almost 365 times per year. For most of the Air Pollution Disasters, subsidence inversion was the culprit as such inversions may extend through the friction layer to heights of over 1500m also and when it drops to less than 200m, extreme pollution occurs. Thus the subsidence inversion occurs at modest altitudes due to the sinking or subsiding of air in anticyclones (high pressure areas surrounded by low pressure areas). The circulating air descends slowly at a rate of about 1 km per day and forms a blanket of 'warm layer'. Sometimes a combination of these two inversions occurs and such phenomenon is called 'DOUBLE INVERSION' as shown in fig. 5.4 (c).

### 5.11 MAXIMUM MIXING DEPTH (MMD)

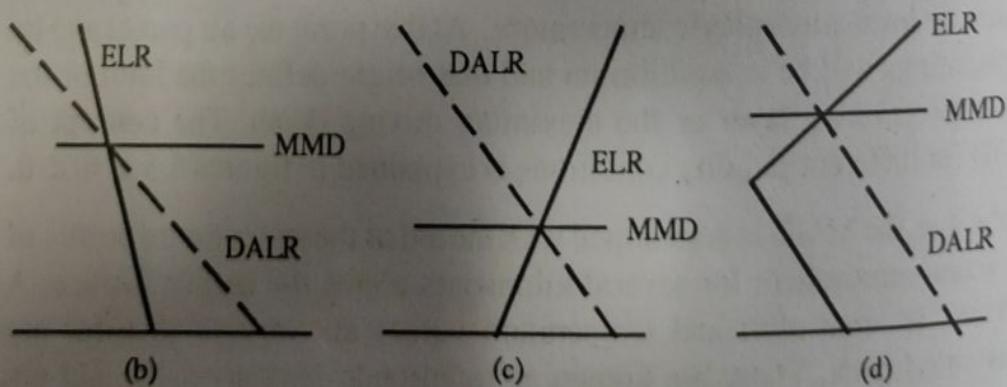
Once air pollutants are released into the atmosphere their subsequent fate i.e. dispersion is entirely dependent on the weather conditions. The vertical extent to which the mixing takes place varies diurnally, from season to season, and is also affected by topographical features. The greater the vertical extent , the larger the volume of the atmosphere available to dilute the pollutant concentration. Thermal buoyancy effects determine the depth of the convective mixing layer, which is called the Maximum Mixing Depth (MMD). The MMD values available as an average for a period of 1 month are known as Mean Maximum Mixing Depths (MMMD).

When an air parcel is heated by solar radiation at the earth's surface, its temperature rises above that of the surrounding air. After heating, the air parcel will continue to rise within the local atmosphere until its temperature equals the local atmospheric temperature. At that point the air parcel and its surroundings will be in equilibrium and that height defines the limit of the convective mixing layer or the maximum mixing depth. The concept of MMD for different stability conditions is explained in figures 5.5 a, b, c, d.

In practice, the MMD is determined with the aid of the temperature profile of the actual atmosphere for several kilometers above the earth's surface. A balloon is sent aloft and temperature values at various altitudes are transmitted back. These are known as radiosonde measurements and are plotted versus height. A dry adiabatic temperature line, starting at the maximum surface temperature for that month , is also drawn on this plot. The altitude at which this dry adiabatic line intersects the radiosonde measure-



**Fig.5.5(a)** Computation of Mixing Depth  
in a Typical Environment



**Fig.5.5(b) (c) (d) :** Maximum Mixing Depth  
in Different Environments

ments is taken as the MMD. Temperature sounding data are usually taken at night but morning data are also frequently measured.

The values of the MMD are usually low at night and increase during the daylight hours. Under a severe inversion at night, the value may be essentially zero while values upto 2000 and 5000m are common in the day time. On a seasonal basis the mean MMD is at a minimum in the winter (December and January) and at a maximum during the summer (May and June). It has been noted that extensive urban air pollution episodes frequently occur when the MMD value is less than 1500m. Since values less than this are quite common in many urban areas, the potential for air pollution episodes is often high. Before locating an industry, it should be seen that the MMD values are not less than 2000m. On similar lines the minimum mixing depth, which normally occurs before sun rise is obtained by adding 5°C to the minimum surface temperature as shown in figure.

### 5.12 PLUME BEHAVIOUR

The geometric forms of stack plumes are a function of the vertical temperature and wind profiles; vice versa, by looking at the plume one can state stability condition and the dispersive capacity of atmosphere. The behaviour and dispersion of a plume entirely depend on the environmental lapse rate, ELR. A parcel of air released from a stack into the atmosphere follows the

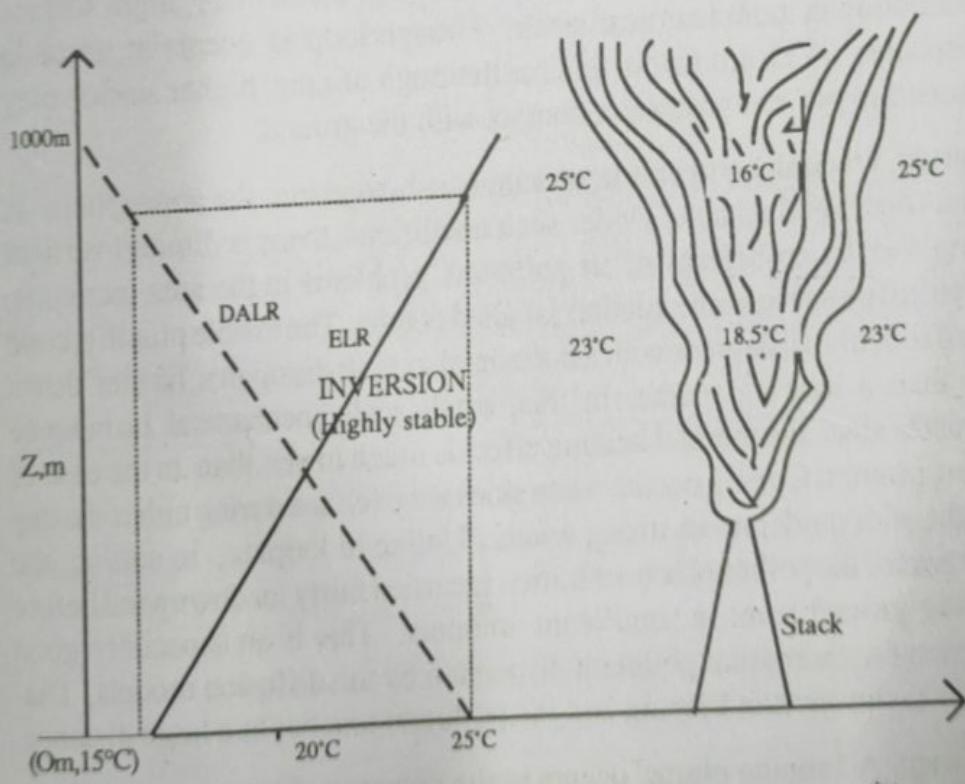


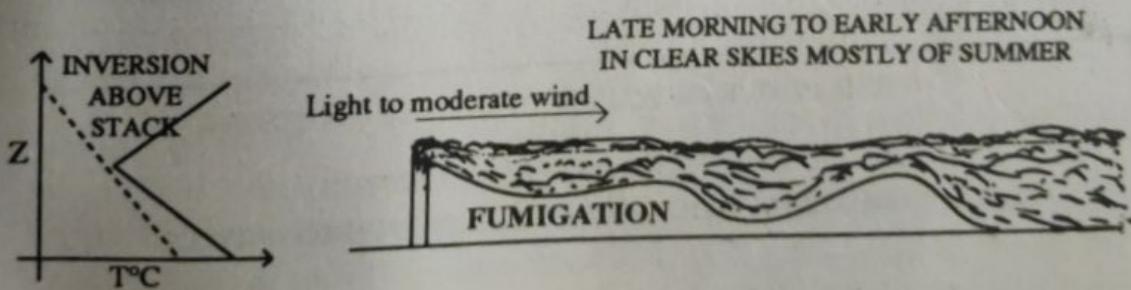
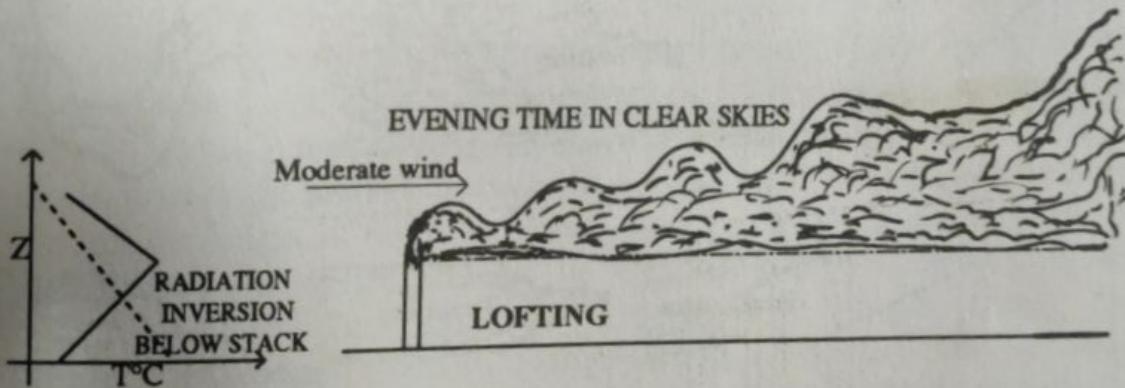
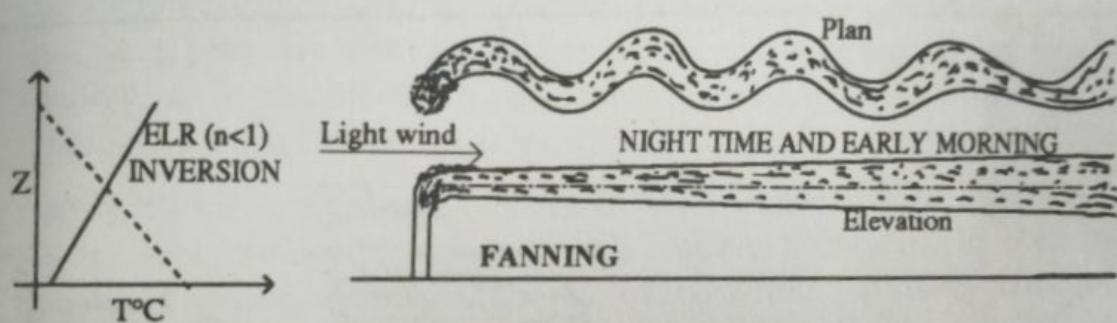
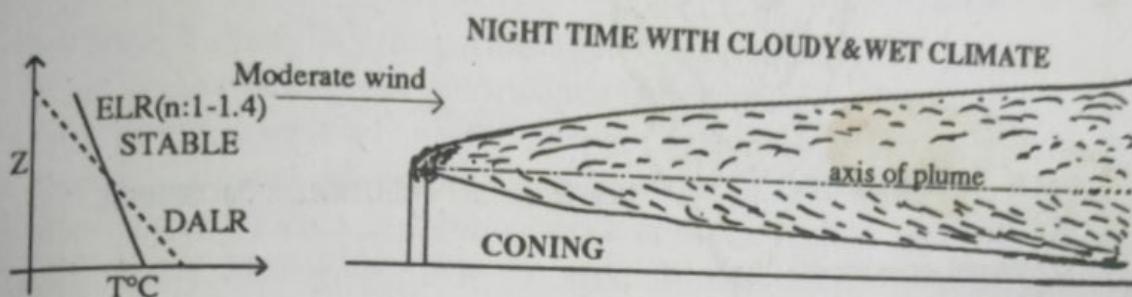
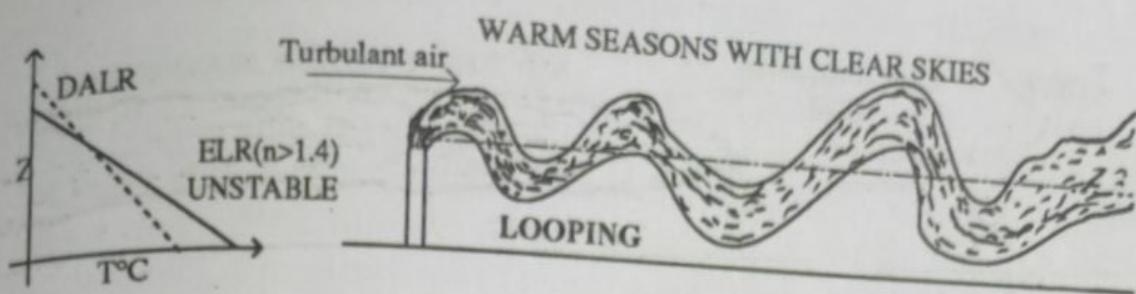
Fig. 5.6 Effect of Inversion on Plume Behaviour

dry adiabatic lapse rate, DALR and attains a temperature of about  $16^{\circ}\text{C}$ , as explained in figure 5.6(depending on surface temperature and altitude). But the surrounding environmental temperature will be about  $25^{\circ}\text{C}$ . Thus the denser parcel of air cannot raise upwards in the warmer and lighter atmosphere. Thus, inversion is the most unfavourable condition for the dispersion of pollutants in atmosphere. Similarly, in superadiabatic atmospheres ( $n > 1.4$ ) the temperature in the environment would decrease at a faster rate of say  $1.5^{\circ}\text{C}/100\text{ m}$  whereas the plume temperature would be decreasing at the standard rate of  $1^{\circ}\text{C}/100\text{ m}$ . Due to this, a plume or parcel of air released from a stack is at a higher temperature than its surrounding environmental temperature. Thus, the parcel of air owing to its lower density is continuously buoyed upwards. Such atmosphere is called unstable atmosphere in which the pollutant dispersion is good and ground level concentrations are less. The plume behaviour is shown in figure 5.7. The plume behaviour in a given environment may be different for stacks of different heights.

**Looping:** It is associated with turbulent air during warm seasons with clear skies. It occurs under super-adiabatic ( $n > 1.4$ ) conditions and during day time with clear or partly cloudy skies and intense solar heating. In this, irregular loops dissipate in patches and relatively rapidly with distance. It occurs due to light to moderate wind speeds on a hot summer afternoon when large scale thermal eddies are present. These eddies carry portions of the plume to the ground level for short time periods, carrying momentary high surface concentration of pollutant near stack. Though looping occurs in unstable atmospheres which are favourable for thorough mixing, higher stacks may be needed to prevent premature contact with the ground.

**Coning:** When the ambient lapse rate is sub-adiabatic the atmosphere is neutral (or) slightly stable. Under such conditions, there is limited vertical mixing and the probability of air pollution problems in the area increases. The typical plume in such situation is called coning. The visible plume is cone shaped roughly 10 degrees with a horizontal axis. It dissipates further down wind than a looping plume. In this, small scale mechanical turbulence dominates since the thermal heating effect is much lower than in the case of looping plumes. Coning occurs when skies are overcast during either the day or night with moderate to strong winds. Unlike in looping, in coning, the major part of the pollutant concentration is carried fairly far downwind before reaching ground level in significant amounts. This is an especially good condition for estimating pollutant dispersion by the diffusion models. Dispersion is slower than looping and the pollutant touches at a large distance.

**Fanning:** A 'fanning plume' occurs in the presence of large negative lapse rates (inversion and isothermal lapse rate), so that a strong surface inversion



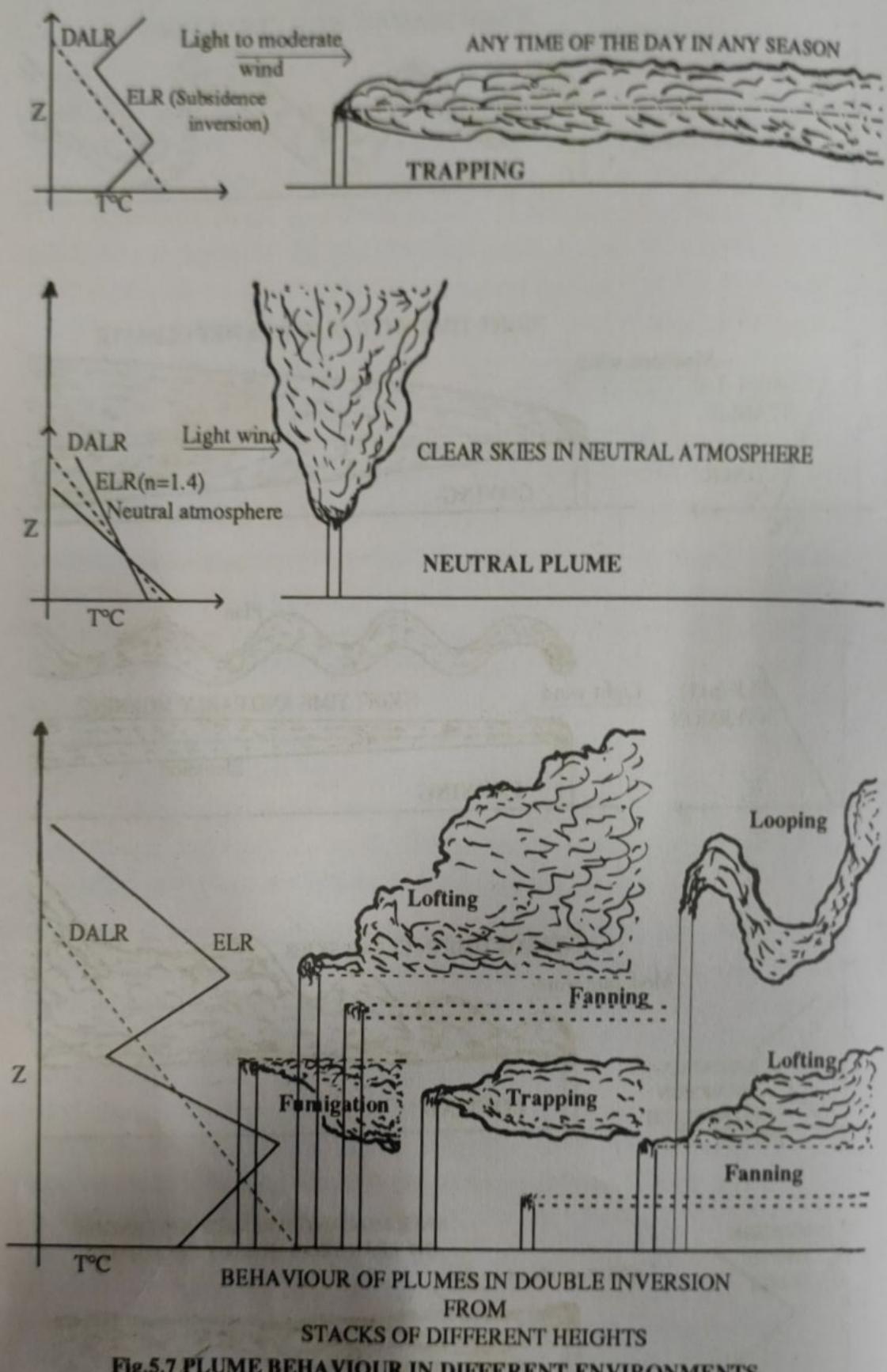


Fig.5.7 PLUME BEHAVIOUR IN DIFFERENT ENVIRONMENTS

takes place at a considerable distance above the stack height. The atmosphere is extremely stable, with very little turbulence and light winds. The typical occurrence of the plume is at night and in early morning conditions when the earth is cooled by outgoing radiation. A fanning plume may appear as a narrow horizontal fan without any vertical spreading for several kilometers downwind. If the effluent is warm, plume rises slowly and then drifts horizontally. The dispersion of plume is very slow, and concentration aloft high at relatively great distance downwind. A small probability of ground contact exists, though turbulence can result in considerable ground contact.

**Lofting:** 'Lofting' prevails in the late afternoon and early evening under clear skies. In the evening (sun sets) radiation from the surface leads to an inversion layer near ground level. As the inversion layer deepens, a lofting plume will change to a fanning plume. Due to the inversion, adiabatic lapse rate forms at stack top which makes the lower layer stable and the upper layer neutral or unstable. The plume is in the form of loops or cone with well defined bottom and diffuses to top. In the upper layer, the winds are of moderate and considerable turbulence and they have very little influence in the layer below. In lofting, probability of ground contact is small unless inversion layer is shallow. It is considered to be the best condition for dispersion since pollutants are dispersed in upper air with small probability of ground contact.

**Fumigation:** Fumigation plumes occur when a stable layer of air lies a short distance above the release point of the plume and an unstable air layer lies below the plume. It occurs during changes from inversion to normal condition and also with sea breeze in late morning or early afternoon. It stays temporarily for maximum 30 minutes except in case of sea-breeze conditions, in which case it stays for several hours. The morning sun heats the ground, which in turn leads to the development of a negative temperature gradient from the ground upward. Once the newly formed unstable layer reaches the height of the stack, large concentrations of stack gas will be carried downwind to the surface. The winds are light to moderate aloft and light below, but thermal turbulence is observed in lower layer only. The ground level concentrations are high especially when plume has stagnated aloft. Fumigation is formed usually under clear skies and light winds, and is more prevalent in the summer. It usually starts when a fanning plume breaks up into a looping plume.

**Trapping:** It occurs in a stable atmosphere, both above and below stack with an unstable atmosphere in between the two inversion layers and can diffuse only in the limited vertical height. It may occur at any time of the day in any season. If associated with subsidence inversion it may persist for months as in Los Angeles and if associated with warm frontal inversions it lasts for less

than a day. It is probably one of the worst pollution situations.

**Neutral Plume:** It tends to raise directly into the atmosphere until it reaches air of density similar to that of plume itself. It is often converted to coning if wind velocity is greater than 10m/sec and when cloud cover blocks the solar radiation by day and terrestrial radiation by night.

### 5.13 EFFECT OF TOPOGRAPHY ON POLLUTANT DISPERSION

Geophysical land forms like mountains, valleys, oceans and other large water bodies and continents over which air masses travel have a great effect on weather, meteorological conditions and finally on the dispersion of air pollutants in the atmosphere, as follows:

#### (A) Effect of Water Bodies on Pollutant Dispersion

During day time land gets heated up by solar rays very easily due to its conductance. The temperature over waters raises very slowly since water does not reradiate solar energy quickly and also since the heat energy received by water penetrates to greater depths. Thus during day time warm air over earth rises upwards and this zone is replaced by colder air over water bodies. This is typically exemplified by the 'Sea Breeze Condition'. This is an example of inversion as temperature increases with elevation. The effect is maximum during afternoons and during summer. The reverse i.e. offshore breeze may also occur during winter nights but the intensity is very less.

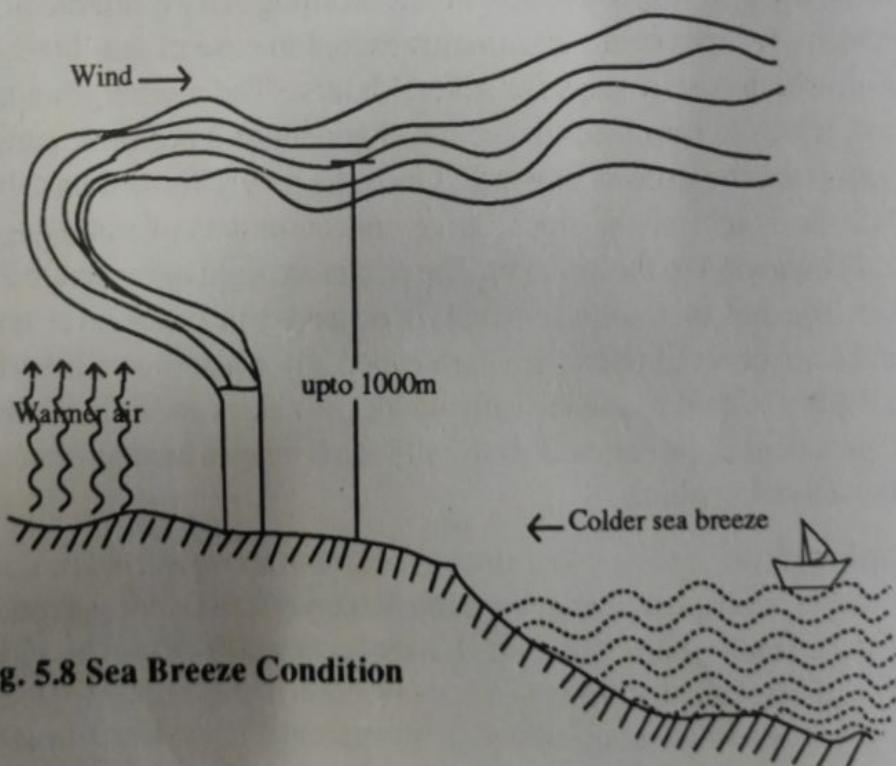


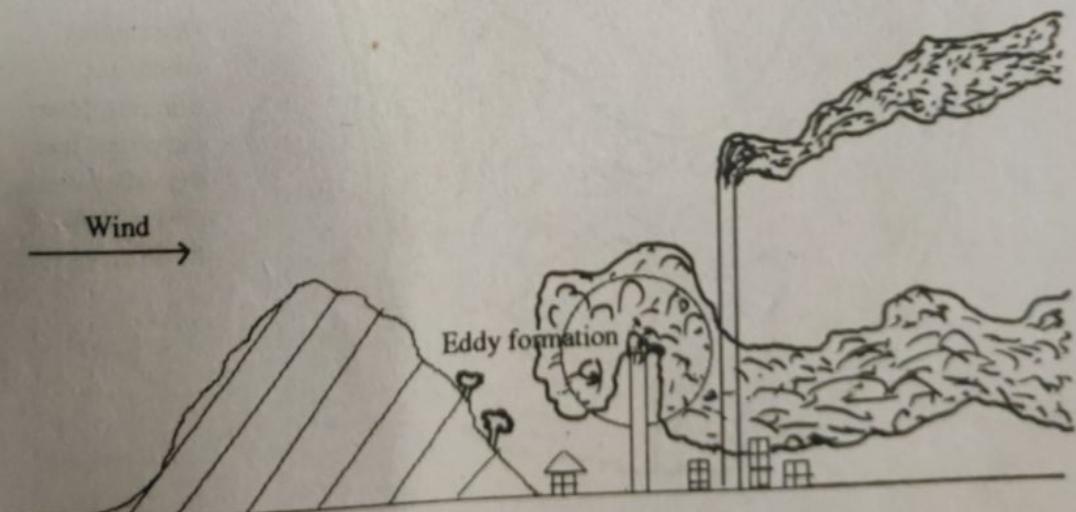
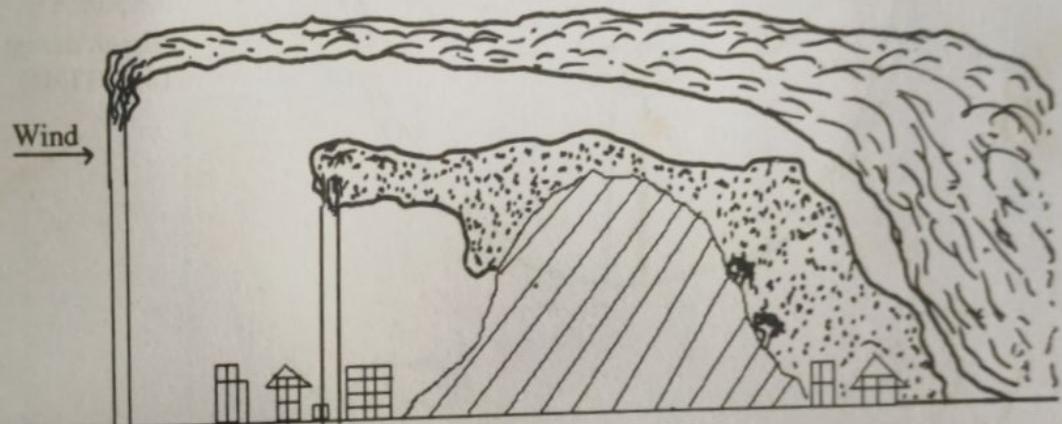
Fig. 5.8 Sea Breeze Condition

### (B) Effect of Ridges/Buildings on Plume Dispersion

Both the above cases may cause dense ground level concentrations.

- Solutions:
1. Increase in stack height by 50% or more may be necessary.
  2. Process reduction during unfavourable wind conditions.
  3. Permanent stack cleaning devices.

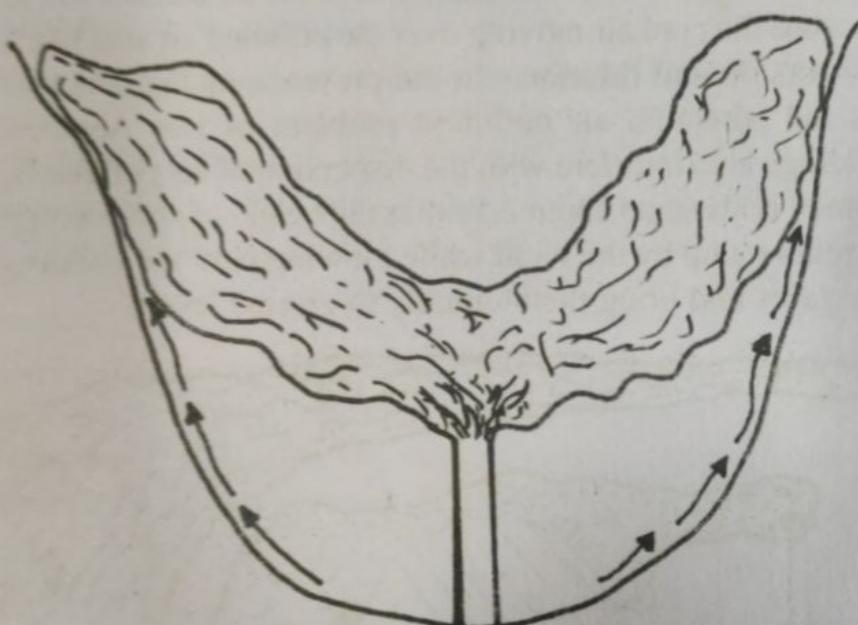
The problem is more severe in coastal regions. When hills surrounding a coastal area form a basin, an intense pollution problem may be created. The cool air blows inland pushing the air pollutants towards the mountains where they are trapped because the cool air moving over the polluted air acts like a lid that prevents dispersion and dilution. In the presence of fog, smog is formed and this is the perennial air pollution problem of Los Angeles. Similarly taller buildings also interfere with the dispersion of air pollutants. If the height of chimney is less than about 2.5 times the height of surrounding buildings, eddy currents set up by the wind while blowing past the building may engulf the flue gases and bring them quickly to ground levels.



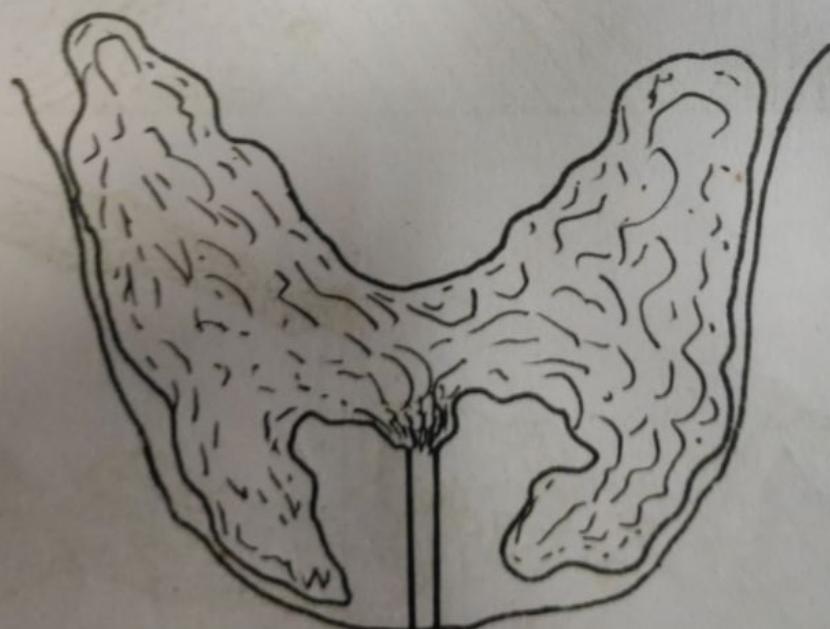
**Fig.5.9 Effect of Ridges/Buildings on Dispersion**

### (C) Effect of Valleys on Pollutant Concentration

A valley tends to channel wind flow along the axis. In valleys, during day time, ground gets heated and warmer air starts ascending both up the valley and along the slopes. Thus the plume from the stack is forced to fan out. The problem is severe during nights when the reverse condition occurs. During nights, the air flows into the valley bringing and depositing the pollutants in the valley leading to high ground level concentrations. When winds are light, the air in the valley becomes stagnant and the problem is acute, especially during winter nights.



Warmer air  
ascending  
along the  
slope forcing  
the plume to  
fan out during  
**DAY TIME**



Descending  
colder air  
bringing down  
the plume into  
the valley during  
inversion in  
**NIGHT TIME**

**Fig. 5.10 Effect of Valleys on Dispersion**

#### (D) Effect of Terrain Roughness on Dispersion

Pollutant dispersion is a function of wind speed which in turn is a function of friction forces which depend upon the terrain roughness. Wind speed is zero at earth's surface and then rises to a gradient value at a height of few hundred meters. If terrain roughness is more, as in case of urbanised and industrialized areas due to high-rise buildings and industries, the wind velocity profile is steeper and reaches deeper into the atmosphere and as the roughness decreases as in rural areas, the depth of the affected layer is less. Thus, dispersion of pollutants is good in rural areas where maximum wind speed is attained in lesser heights. The wind speed, in general, varies as:

$$U_2/U_1 = (Z_2/Z_1)^n \text{ where } n = 0.25 \text{ for unstable atmospheres and}$$

$$n = 0.50 \text{ for stable atmospheres.}$$

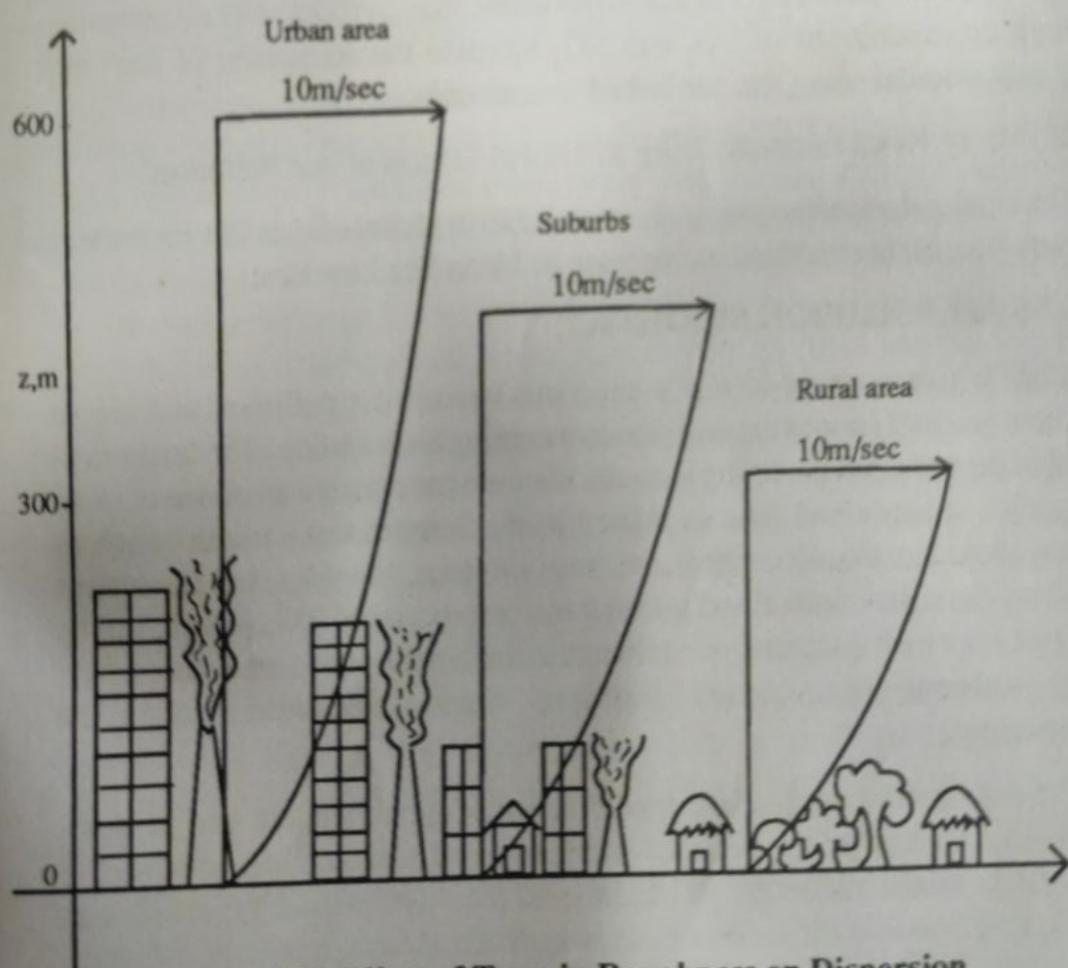


Fig. 5.11 Effect of Terrain Roughness on Dispersion

### 5.14 EFFECT OF AIR POLLUTANTS ON METEOROLOGY

Meteorology has significance on the dispersions of air pollutants. In a similar way, the air pollutants released into the atmosphere by man also have an impact on the atmosphere. They are :

**1. Reduced Visibility:** Visibility is a measure of the transparency of the atmosphere. Reduced visibility presents safety hazards and is aesthetically displeasing. Particulates of size  $0.38$  to  $0.76\mu\text{m}$  and gas molecules, especially sulphur dioxide, are the major contaminants to reduce visibility. These pollutants absorb and scatter light. Scattering reduces visibility by decreasing contrast between the object and the background sky. Scattering of light by small particles is also responsible for the reddish haze of sunsets.

**2. Increase in Precipitation:** Small particulates act as nuclei, inducing the formation of raindrops from condensation. Due to massive emission rates of particulates into the atmosphere from urban areas, they are fogger and rainier than their rural surroundings. The occurrence of fog over cities is double the incidence of fog over rural areas. Similarly, cloud formation provides 10% more cover in skies over cities than in those over countryside. High concentrations of  $\text{SO}_2$  and  $\text{NO}_2$  increase the formation of fog and photochemical smog and are linked to acid rains.

**3. Urban Heat Islands:** Refer to 'Global Effects of Air Pollution'.

Thus, these three effects may cause cumulative global effects like increase in earth's ambient temperature, increase in Mean Sea Level etc.

### 5.15 AIR POLLUTION MODELING

Models give answers to many questions concerning pollution and are an important tool for making decisions concerning air pollution. The fundamental of air pollution modeling is to calculate air concentrations of one or more species in space and time as related to the independent variables such as emissions into the atmosphere, the meteorological variables, and parameters which describe removal and transformation processes. This is achieved by a system which quantitatively relates the concentrations to other parameters by mathematical or physical methods. Such a procedure is called the modeling.

The selection of appropriate model depends upon their use and purpose. Having determined the need for and purpose of a model, it is necessary to consider model attributes. An ideal model should be physically realistic and accurate, suitable for various meteorological and topographical conditions, suitable for various emission sources (point, area, line) and suitable for various air pollution species. But unfortunately such an " Ideal " model does