

SYLLABUS

Anna University, Chennai

AIR POLLUTION AND CONTROL ENGINEERING

UNIT I INTRODUCTION

7

Structure and composition of Atmosphere – Definition, Scope and Scales of Air Pollution – Sources and classification of air pollutants and their effect on human health, vegetation, animals, property, aesthetic value and visibility - Ambient Air Quality and Emission standards.

UNIT II METEOROLOGY

6

Effects of meteorology on Air Pollution - Fundamentals, Atmospheric stability, Inversion, Wind profiles and stack plume patterns- Atmospheric Diffusion Theories – Dispersion models, Plume rise.

UNIT III CONTROL OF PARTICULATE CONTAMINANTS

11

Factors affecting Selection of Control Equipment – Gas Particle Interaction – Working principle - Gravity Separators, Centrifugal separators Fabric filters, Particulate Scrubbers, Electrostatic Precipitators.

UNIT IV CONTROL OF GASEOUS CONTAMINANTS

11

Factors affecting Selection of Control Equipment – Working principle - absorption, Adsorption, condensation, Incineration, Bio filters – Process control and Monitoring

UNIT V INDOOR AIR QUALITY MANAGEMENT

10

Sources, types and control of indoor air pollutants, sick building syndrome and Building related illness- Sources and Effects of Noise Pollution – Measurement – Standards – Control and Preventive measures

TOTAL: 45 PERIODS

INTRODUCTION

1.1. INTRODUCTION

The clean air is very essential for human life and human health. It should be free from pollutants in any form. The pollutants may be in the form of solid, liquid or gaseous form. Any considerable change in the composition of air may affect the living system of the humans.

Air Pollution is defined as the pollution in the atmospheric air, due to the presence of solid, liquid, or gaseous material and causes the problems to humans, living systems, plants etc.

A Pollutant is defined as a material (or substance) which creates the air pollution and in the form of liquid, gaseous or solid. Generally, any pollutant, solid, liquid or gaseous material affects the atmospheric air considerably and creates harmful effects on the environment.

1.2. STRUCTURE AND COMPOSITION OF ATMOSPHERE

The **atmosphere of earth** is a layer of gases, surrounding the planet Earth, which is retained by gravitational force of the earth. It extends to about 500 km from the Earth's surface.

Generally, the air contains 78.09% Nitrogen, 20.95% Oxygen, 0.93% Argon, 0.039% Carbon-di-oxide and fewer amounts of other gases.

The study of Earth's atmosphere and the process is called **Aerology or Atmospheric Science**.

1.2.1. Structure of Atmosphere

Earth's atmosphere can be divided into five main layers. From the lowest to highest, these layers are,

1. Troposphere (0 to 12 km)
2. Stratosphere (12 to 50 km)
3. Mesosphere (50 to 80 km)
4. Thermosphere (80 to 500 km)
5. Exosphere (above 500 km)

1. Troposphere

Troposphere is the nearest gaseous layer and the lowest layer of the atmospheric Earth, extending from the Earth's surface up to an average distance of about 12 km. This altitude actually varies from about 9 km (30000 ft) at the poles to 17 km (56,000 ft) at equator, with some variations due to weather.

Solar radiation is the main heat source and it is absorbed at the ground level and hence, the temperature decreases with increase in height of the troposphere.

The rate at which the temperature decreases with the increase in height is called **Lapse Rate**, and which is about $5^{\circ}\text{C}/\text{km}$.

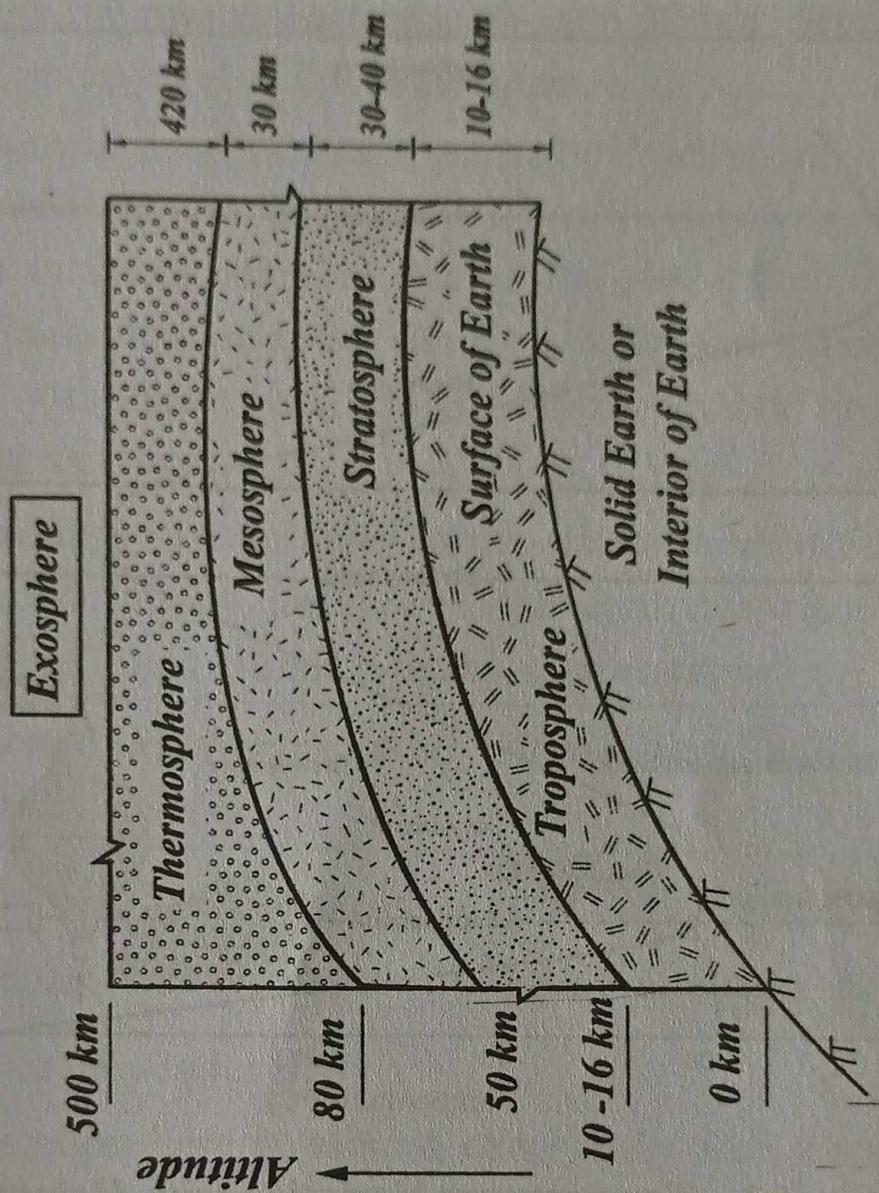


Fig. 1.1. Structure of the Atmosphere

Most of the water vapour, clouds and storms of the atmosphere exist in this troposphere. **Tropopause** is the top level of the troposphere (figure 1.1).

Approximately, 80% of the mass of the earth's atmosphere is only troposphere. It is the denser layer than all other layers, because larger atmospheric weights acts on the top of the troposphere and make it to be most severely compressed. 50% of the total mass of the atmosphere is located in the lower 5.6 km (18,000 ft) of the troposphere.

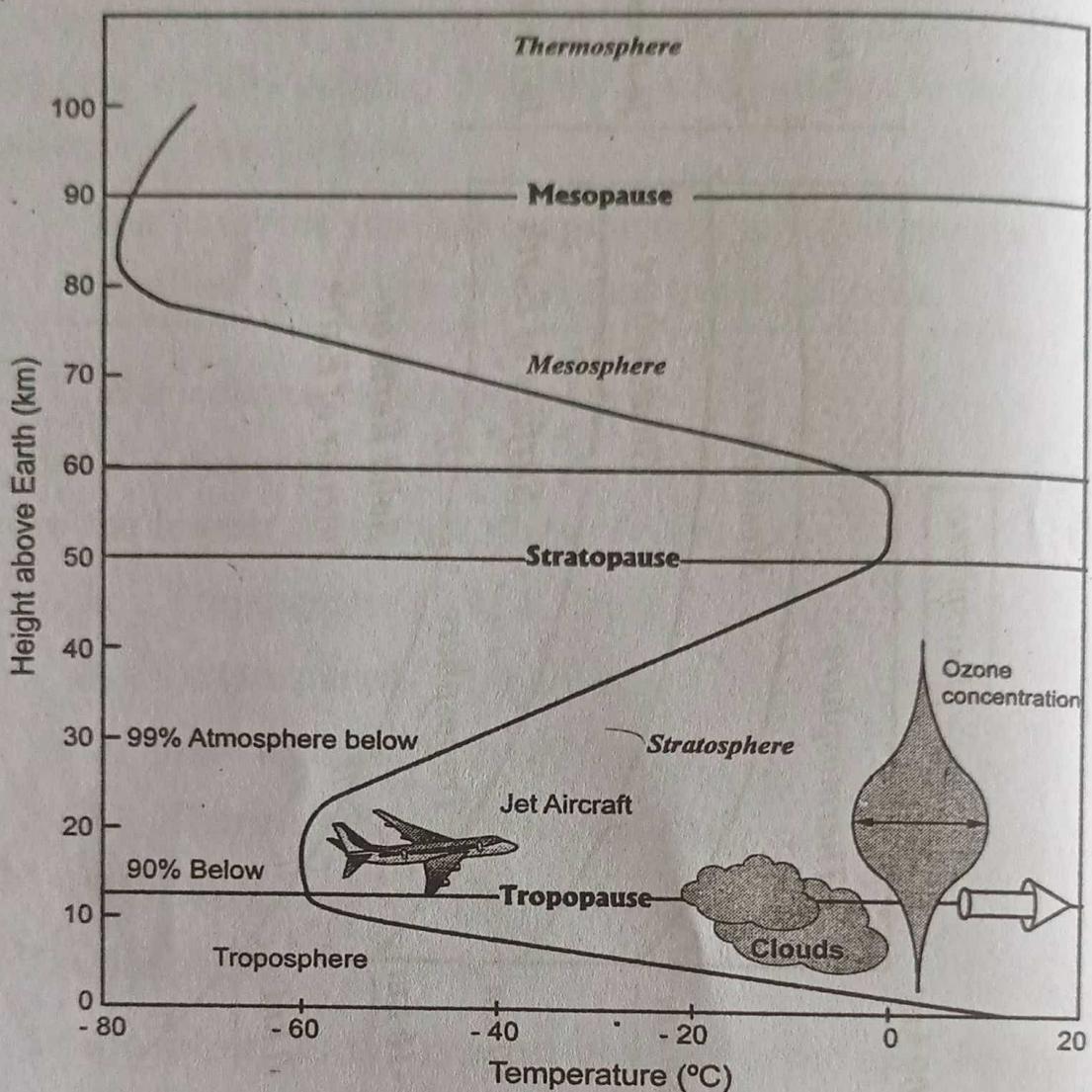


Fig. 1.2. Temperature Variation with Height

Troposphere is primarily consists of 70% of Nitrogen and 21% of Oxygen with only small concentrations of other gases.

Most conventional aviation activity takes place in the troposphere and it is the only layer that can be accessed by **Propeller-Driven Aircraft**.

2. Stratosphere

The **Stratosphere** is the second layer of Earth's atmosphere, just above the troposphere (**Tropopause - TP**)

and below the mesosphere extending to 50 km. **Stratopause (SP)** is the top level of the stratosphere .

The temperature increases gradually from about -80°C to 0°C between the Tropopause (TP) to Stratopause (SP). The increase in temperature is due to the absorption of **Ultra-Violet Radiation** from the sun by oxygen and ozone, which restricts turbulence and mixing. There is very little water vapour at this layer.

Ozone layer is the layer in the stratosphere which exists between 20 km 40 km above the earth's surface. Hence stratosphere is sometimes referred as **ozonosphere**.

Ozone layer protects all Ultra-Violet Radiation from the Sun.

The atmospheric pressure at the top of the stratosphere (Stratopause) is approximately equal to $\frac{1}{1000}$ times the pressure at the sea level.

The stratosphere is almost completely free from clouds and other forms of weather. However, **Polar stratospheric** or **Nacreous clouds** are occasionally seen in the lower parts of the stratosphere, where the air is cold. This is the highest layer that a **Jet-Powered Aircraft** can be accessed.

3. Mesosphere

The **Mesosphere** is the third layer from the Earth's surface, extending from stratosphere of about 50 km to 80 km from the ground surface. It is the coolest place of the earth's atmosphere and has an average temperature of about -85°C .

The top level of the mesosphere is called **Mesopause** (MP) and just below the mesopause, the air is highly cold. Within the mesosphere, the temperature decreases with increasing altitude. This is due to the increasing cooling by CO₂ relative emission and due to decreasing solar heating.

The mesosphere lies above the maximum altitude for aircraft and below the minimum altitude for orbital spacecraft. It has been only accessed through the use of sounding rockets. As a result, it is the most poorly understood part of the atmosphere.

The stratosphere, mesosphere and the lowest part of the atmosphere is collectively referred as '**Middle Atmosphere**', which has the altitudes approximately from 10 km to 100 km above the earth's surface.

4. Thermosphere

Thermosphere is the zone above the **mesopause**, and it extends that an altitude of about 80 km up to 500 km of the **Thermopause**. The height of the thermopause varies considerably due to the changes in solar activity. The thermopause lies at the lower boundary of the exosphere and it is also called as **Exobase**.

The lower part of the thermosphere (from 80 to 480 km above the earth's surface) contains many ions and free electrons. Cosmic rays and radiations from the sun produce the ions and this part of the thermosphere is called as **ionosphere**.

Depending upon the degree of ionization, the ionosphere is differentiated as follows.

1. D - Region Ionosphere (80 to 95 km altitude)
2. E - Region Ionosphere (95 to 140 km altitude)
3. F₁ - Region Ionosphere (145 to 305 km altitude)
4. F₂ - Region Ionosphere (305 to 480 km altitude)

This atmospheric layer undergoes a gradual increase in temperature with height. The temperature of this layer can rise as high as 1500° C. This layer is completely cloudless and free from water vapour.

The **International Space Station**, orbits in this layer between 320 and 380 km altitude from the earth's surface.

5. Exosphere

The outermost layer (or region) of the atmosphere, beyond the height of 500 km and above is called **Exosphere**. It is a low density, high temperature region with minimum atomic collisions. The exosphere merges with the emptiness of outer space, where there is no atmosphere.

This layer is mainly composed of extremely low densities of H₂, He and other heavier molecules such as N₂, O₂ and CO₂ closer to the exobase. The exosphere is located too far above the Earth, for any meteorological factor to be possible. Most of the satellites, orbiting the earth are located in the exosphere.

1.2.2. Other layers

Within the primary layers, which are differentiated by temperature, several secondary layers are also distinguished by other properties, and as follows.

1. Ozone Layer
2. Ionosphere
3. Magnetosphere
4. Homosphere and Heterosphere etc.
5. Planetary Boundary Layer

1. Ozone layer

Ozone layer exists within the stratosphere. In this layer, the concentrations of ozone is about 2ppm to 8 ppm, which is little higher than in the lower atmosphere. However, it is very small, when compared to the atmosphere. It is located in the lower portion of the stratosphere from about 20 km to 40 km above the Earth's surface. The thickness ozone layer varies seasonally and geographically. About 90% of the ozone in the atmosphere is contained in the stratosphere.

2. Ionosphere

Ionosphere is a region of the atmosphere that is ionized by solar radiation. During daytime, it stretches from 50 to 1,000 km and includes the mesosphere, thermosphere and parts of the exosphere. However, ionization in the mesosphere largely ceases during the night, so **auroras** are normally seen only in the thermosphere and lower exosphere.

An **aurora** is a natural light display in the sky, especially in the high latitude (Arctic and Antarctic) regions, caused by the collision of **solar wind** and **magnetosphere** charged particles with the high altitude atmosphere.

3. Magnetosphere

The ionosphere forms the inner edge of the **magnetosphere**. It has practical importance because it influences, for example, radio propagation on Earth.

4. Homosphere and Heterosphere

The **homosphere** and **heterosphere** are defined by whether the atmospheric gases are well mixed. The surface based homosphere includes the troposphere, stratosphere, mesosphere, and the lowest part of the thermosphere, where the chemical composition of the atmosphere does not depend on molecular weight because the gases are mixed by turbulence. This relatively homogeneous layer ends at the **turbopause** which is found at about 100 km, which places it about 20 km above the mesopause.

Above this altitude lies the heterosphere, which includes the exosphere and most of the thermosphere. Here, the chemical composition varies with altitude. This is because the distance that particles can move without colliding with one another is large compared with the size of motions that cause mixing. This allows the gases to stratify by molecular weight, with the heavier ones such as oxygen and nitrogen present only near the bottom of the heterosphere. The upper part of the heterosphere is composed almost completely of hydrogen, the lightest element.

5. Planetary boundary layer

The **planetary boundary layer** is the part of the troposphere that is closest to Earth's surface and is directly affected by it, mainly through turbulent diffusion. During the

day the planetary boundary layer usually is well-mixed, whereas at night it becomes stably stratified with weak or intermittent mixing. The depth of the planetary boundary layer ranges from as little as about 100 meters on clear, calm nights to 3000 m or more during the afternoon in dry regions.

1.2.3. Elements of Atmosphere

The three major constituents of Earth's atmosphere are Nitrogen, Oxygen, and Argon. Water vapor accounts for approximately 0.25% of the atmosphere by mass. The concentration of water vapor (a greenhouse gas) varies significantly from around 10 ppm by volume in the coldest portions of the atmosphere. In order to know the air pollution and its control, it is very important to know the composition of the atmosphere, and it is given in Table 1.1.

The composition of the atmosphere is not static and it changes according to the time and place.

Nitrogen and oxygen are the two main gases in the atmosphere and 99 percentage of the atmosphere is made up of these two gases.

Gases form of water present in the atmosphere is called **water vapour** and it is the source of all kinds of precipitation. The amount of water vapour decreases with altitude. It also decreases from the equator (or from the low latitudes) towards the poles (or towards the high latitudes). Carbon dioxide (and water vapour) is found only up to 90 km from the surface of the earth.

Dust particles are generally found in the lower layers of the atmosphere. These particles are found in the form of sand, smoke-soot, oceanic salt, ash, pollen, etc.

Table 1.1. Composition of Air

Sl. No	Gas	Concentration in ppm by Volume	Concentration of % by Volume
1.	Nitrogen (N_2)	280000	78.09 ± 0.004
2.	Oxygen (O_2)	209500	20.946 ± 0.002
3.	Argon (Ar)	9300	0.934 ± 0.001
4.	Carbon-Di- Oxide (CO_2)	320	0.033 ± 0.001
5.	Neon (Ne)	18	0.0018
6.	Helium (He)	5.2	
7.	Methane (CH_4)	1.5	
8.	Krypton (Kr)	1.0	
9.	Hydrogen	0.5	
10.	N_2O	0.2	
11.	Carbon Monoxide (CO)	0.1	
12.	Xenon (Xe)	0.08	
13.	Ozone	0.02	
14.	NO_2	0.001	
15.	NH_3	0.006	

The sun radiates its energy in all directions into space in short wavelengths, which is known as **Solar Radiation**.

The energy received by the earth's surface in the form of short waves is termed as **Incoming Solar Radiation or Insolation**.

1.3. AIR POLLUTION

Air pollution is one of the important pollution amongst the environmental pollution. The air should be fresh and clean.

Air pollution impairs health, reduces visibility, creates death, brings about huge economic losses and contributes to the general deterioration. Hence the study of air pollution is very important. The study of air pollution helps to understand the sources, effects and control of air pollution.

1.3.1. Scales of Air Pollution

Air Quality Index (AQI), (or Pollutant Standards Index (PSI)), is a uniform system developed by United States - EPA, to enable the public to determine whether air quality levels in a particular location are good, moderate, unhealthful, or worse.

The AQI is used as an information tool to advise the public. It is often presented along with the weather report in local newspapers. The AQI describes the general health effects associated with different pollution levels, as well as necessary precautionary steps may need to be taken if air pollution levels rise into the unhealthful range.

The AQI measures five criteria air pollutants (Particulate Matter, Sulphur Di-Oxide, Carbon Monoxide, Nitrogen Di-Oxide and Ozone), and converts the measured pollutant concentrations in a community's air to a number on a scale of 0 to 500.

The intervals on the AQI scale relate to the potential health effects of the daily concentrations of each of these five pollutants. The most important number on this scale is 100, since this number corresponds to the National Ambient Air Quality Standard established under the Clean Air Act, 1970.

1. AQI level in excess of 100 means that a pollutant is in the unhealthful range on a given day
2. AQI level at or below 100 means that a pollutant reading is in the satisfactory range.

The following table 1.2 was constructed by the EPA to identify the health effects associated with different levels of air pollution, along with the cautionary statements that would be appropriate if air pollution in a community were to fall into one of the "unhealthful" categories on the AQI scale.

Table 1.2. AQI scale and General Health Effects

General Health Effects and Cautionary Statements			
Index Value	AQI Descriptor	General Health Effects	Cautionary Statements
Up to 50	Good	None for the general population.	None required.
50 to 100	Moderate	Few or none for the general population.	None required.

100 to 200	Unhealthful	Mild aggravation of symptoms among susceptible people, with irritation symptoms in the healthy population.	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity. General population should reduce vigorous outdoor activity.
200 to 300	Severe Unhealthful	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease; widespread symptoms in the healthy population.	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity. General population should avoid vigorous outdoor activity.
Over 300	Hazardous	Early onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. At AQI levels above 400,

		<p>At AQI levels above 400, premature death of ill and elderly persons may result. Healthy people experience adverse symptoms that affect normal activity.</p>	<p>general population should avoid outdoor activity. All people should remain indoors, keeping windows and doors closed, and minimize physical exertion.</p>
--	--	--	--

1.4. SOURCES OF AIR POLLUTION

The sources of air pollution can be classified as,

1. Natural Sources
2. Man-Made Sources

1.4.1. Natural Sources

The lower atmosphere of the earth extends to about 13 km above the earth's surface. In the lower atmosphere, water vapour and other variable gaseous materials of natural origin pollute the atmosphere. Various natural sources of air pollution are listed below.

1. NO_2 from electrical storms
2. HF and HCl from volcanoes
3. H_2S , SO_2 from volcanoes
4. Dust and aerosols consist of salts from sea water.
5. Air borne particles from soil and vegetation.

The above natural air pollutants pollute atmospheric air in greater level and they are caused due to the volcanic action, smoke of forest fires, mineral particles from erosion of rock surfaces and have particles from vegetation.

In the lower atmosphere, natural chemical reactions take place which converts gases or vapours into solids and liquids by oxidation, combustion and condensation or polymerization mechanism.

In the upper atmosphere, photo chemical reactions may break down more complex molecules by absorption of high energy **ultra-violet solar radiation** and resultant oxidation, atomic and free radial chain reactions. Most of the Hydrogen Sulphide (H_2S) liberated to the atmosphere comes from natural sources, which is an estimated about 300 million tons per year.

Carbon-di-oxide (CO_2) gas is released by all forms of life during respiration and is assimilated by green plants in **photosynthesis**.

Oxides of nitrogen which are discharged to the atmosphere from the combustion of fuels and industrial process are high reactive chemically and form products that have relatively short life.

1.4.2. Man Made Sources

The important sources of air pollution are the combustion products of fuels such as gases, coals and exhaust gases from vehicles. Due to industrial activities, the air gets highly polluted.

The above factors are listed below.

1. Burning of fossil fuels
2. Burning of forests to clear the land
3. Industrial activities etc.

1.4.3. CAUSES OF AIR POLLUTION

Following are the important causes of air pollution.

1. Population

Fuel consumption has been increased due to the high increase in population rate, and hence the air gets polluted.

2. Industrial Development

Rapid industrial development is one of the major causes of air pollution. The smokes from factories, furnaces, steam engines etc. are some of the common sources of air pollution.

3. Radio-active materials

Following are the important and dangerous sources from radio-active materials.

1. Discharges (or leakages) from nuclear reactor.
2. Evolution of radio-active gases
3. Suspended radio-active dusts from atomic explosions.

4. Natural Causes

Some of the natural causes such as grand dust, vegetation, cosmic dust, H_2S evolution and salt sprays from seas, cause the air pollution.

5. Increase in transport facilities

Rapid increase in automobiles such as cars, motor-vehicles, trains etc. increase the air pollution. The exhaust fumes from the automobiles cause the pollution of atmospheric air in cities.

Air pollution created by the automobiles is called as disease of wealth.

1.5. CLASSIFICATION OF AIR POLLUTANTS

The air pollutants present in the atmosphere can be classified based on the following.

1. Classification based on the origin.
 - (i) Primary Air Pollutants
 - (ii) Secondary Air Pollutants
2. Classification based on the chemical composition.
 - (i) Organic Compounds
 - (ii) In-Organic Compounds
3. Classification based on the state of matter.
 - (i) Particulate Pollutants
 - (ii) Gaseous Pollutants.

1.5.1. Classification Based on Origin

According to the origin of air pollutants, these are classified as,

- a. Primary Air Pollutants
- b. Secondary Air pollutants

I. Primary Air Pollutants

Pollutants, directly emitted from the identifiable sources are called **primary air pollutants**.

The following are the important pollutants causing 90% of the global air pollution.

1. Oxides of Sulphur (SO_2 etc.)
2. Oxides of Carbon (CO , CO_2 etc.)
3. Oxides of Nitrogen (NO , NO_2 , generally NO_x)
4. Volatile Organic Compounds (Generally hydrocarbons)
5. Other Pollutants
 - (a) H_2S
 - (b) H_2F
 - (c) Methyl and Ethyl mercaptans

II. Secondary Air Pollutants

Primary pollutants react with one another or with water vapour in the presence of sunlight forms, a new form of pollutant, called **secondary pollutants**.

Secondary pollutants are more harmful than the primary pollutants. Various secondary pollutants are as follows.

- a. Sulphuric Acid (H_2SO_4)
- b. Ozone (O_3)
- c. Formaldehydes
- d. Peroxy-Acyl-Nitrate (PAN) etc.

Sulphuric Acid (H_2SO_4)

It is formed by the chemical reaction between H_2O and SO_2 . It is more toxic than SO_2 .

O_3 , Formaldehydes and PAN

The above secondary pollutants are formed by the Photo-chemical reactions, in the presence of sunlight.

1.6. IMPORTANAT AIR POLLUTANTS

1.6.1. Oxides of Sulphur

Sulphur-di-oxide and sulphur-tri-oxide are the pollutants in the oxides of sulphur and SO_2 is the harmful one.

SO_2 is an irritant gas and it is a major air pollutant emitted from various man-made sources, causes very serious effects on human beings.

1. It increases the breathing rate and creates the O_2 deficiency in blood circulation.
2. Asthma patients are affected very worst due to this pollutant.
3. SO_2 is also responsible for causing acidity in fogs, smokes and in rains and major sources of corrosion of buildings and metallic materials.

When SO_2 reacts with Oxygen, it forms Sulphur-tri-oxide. This SO_3 may dissolve in body fluid and forms H_2SO_4 , which is a strong and corrosive acid.



H_2SO_4 causes high irritation at lower concentrations and leading to **Broncho-Spasm**.

Sources of SO_2

1. Refineries
2. Chemical plants
3. Smelting Operations
4. Burning of fossil fuels
5. Thermal power plants

6. Open burning of garbage
7. Incineration plants of municipalities.

Limit of SO₂

As per the **Indian Ambient Air Quality Standards**, the annual and 24 hours concentration of SO₂ for industrial residential, rural and other areas is given as 50 and 80 µg/m³ respectively.

Methods to Measure SO₂

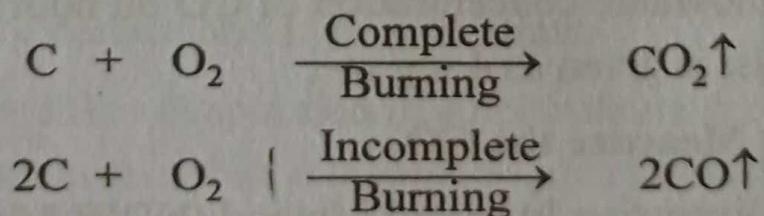
1. Modified West-Gaeke's Method
2. Ultra-Violet Fluorescence Method

1.6.2. Carbon Monoxide (CO)

Carbon Monoxide is a colourless, odourless and toxic gas, produced when the organic materials (such as coal, wood etc.) are burnt incompletely.

Sources of CO

When these organic materials burnt completely, the carbon present in such materials get oxidized completely and forms carbon-di-oxide (CO₂) and the incomplete combustion leads to CO.



The exhausts from the automobile vehicles are also important and major sources of carbon monoxide pollutants in air.

Effects of CO

Carbon monoxide has a greater blood-affinity property and which has been affected by **blood hemoglobin** 200 times more than O_2 . This CO, replaces the O_2 present in the hemoglobin and forms **Carboxy-hemoglobin**. ($CO.H_b$).

If the quantity of **Carboxy-hemoglobin** is less, it produces the little headache, reduction in reaction time etc. on human beings.

If the quantity of $CO.H_b$ concentration is high, it creates difficulty in breathing, heart problems etc. Also, if COH_b .quantity is about 50% of H_b , it makes death of human being.

The death due to the presence of $CO.H_b$ in blood can be easily identified by the appearance of bright pink colour in the human body.

However, CO is not a permanent pollutant and all COs are converted into other harmless compounds, naturally.

Limits of CO

As per the **Indian Ambient Air Quality Standards**, the maximum allowable concentration of CO on hourly weighted average basis, is given as 4 mg/m^3 .

Methods to Measure the CO

1. Non-Dispersive Infra-red Method (NDIR Method)
2. Spectroscopy Method

1.6.3. Nitrogen-Oxides NO_x

During the combustion process of fuels, atmospheric nitrogen combines with Oxygen at high temperatures and

forms Oxides of Nitrogen such as NO, NO₂ and N₂O, generally expressed as NO_x. The nitric oxide (NO) is a very harmful pollutant at high concentrations and may cause sudden death.

The nitrogen oxide again combines with atmospheric Oxygen forms Nitrogen-di-oxide (NO₂). NO₂ is a harmful gas, which irritates the human eyes and nose and creates discomfort in respiration system.

Sources of NO_x

1. Automobile Exhausts
2. Incineration Plants
3. Furnace smokes
4. Combustion of fuel at high temperatures

Methods to Measure NO_x

1. Modified Jacab and Hochheiser Method
2. Gas Phase Chemi-Luminescence Method

1.6.4. Hydrocarbons (HC) and Organic Compounds

Hydrocarbons are the group of simple compounds only consisting of carbon and hydrogen atoms.

They are either evaporated from petroleum fuel supplies or emitted from automobile exhausts when it has not completely burnt.

Methane (CH₄) is an important hydrocarbon which is produced in nature by **bacterial decomposition** in swamps, marshes etc.

Limit of HC

As per new revised **Ambient Air Quality Standards of India**, the maximum permissible limits on annual concentrations of Benzene and Pyrene are $5 \mu\text{g}/\text{m}^3$ and $1 \text{ ng}/\text{m}^3$ respectively.

Test for Hydrocarbons (HCS)

(i) Benzene

- Gas Chromatography (GC) based continuous analyzer method
- Adsorption and Desorption followed by GC Analysis method

(ii) Pyrene

- Solvent extraction followed by HPLC/GC analysis method

1.6.5. Suspended Particulate Matter (SPM)

The particulate substances present in air, may occur in solid form (dust, smoke etc.) and liquid form (mist, fog etc.)

An aerosol is defined as the particle, larger than a molecule but small enough to remain suspended in air.

Dusts are the solid particles generated by handling, crushing grinding of organic or inorganic materials such as rock, ore, metal, coal, wood, grain etc.

A dust may be a solid-particle dispersion aerosol of any particle size.

Total Suspended Particulate Matter (TSPM) is the particles, which includes both liquid and solid particles of suspended particulate matter.

Fig.1.3 shows the types of particulate materials present in air with respect to their sizes.

I. Sources of SPM in Air

1. By natural process such as winds, pollens and pores, volcanic eruptions, decomposition of organic materials etc.
2. By human activities such as mining, burning of fossil fuels, industrial processes etc.

II. Effects of SPM

Larger particles (of size more than 10μ) can be trapped by the hairs, present in the lining of nose and particles from 5μ to 10μ are also trapped by the mucus, and they are sent back by **Spitting (or) Swallowing**.

Very finer particles less than 5μ size reach the lungs and cause the following effects on human respiratory system.

- a. Damages the lung tissues
- b. Causing diseases like Asthma, Bronchitis
- c. Causes Cancer severely

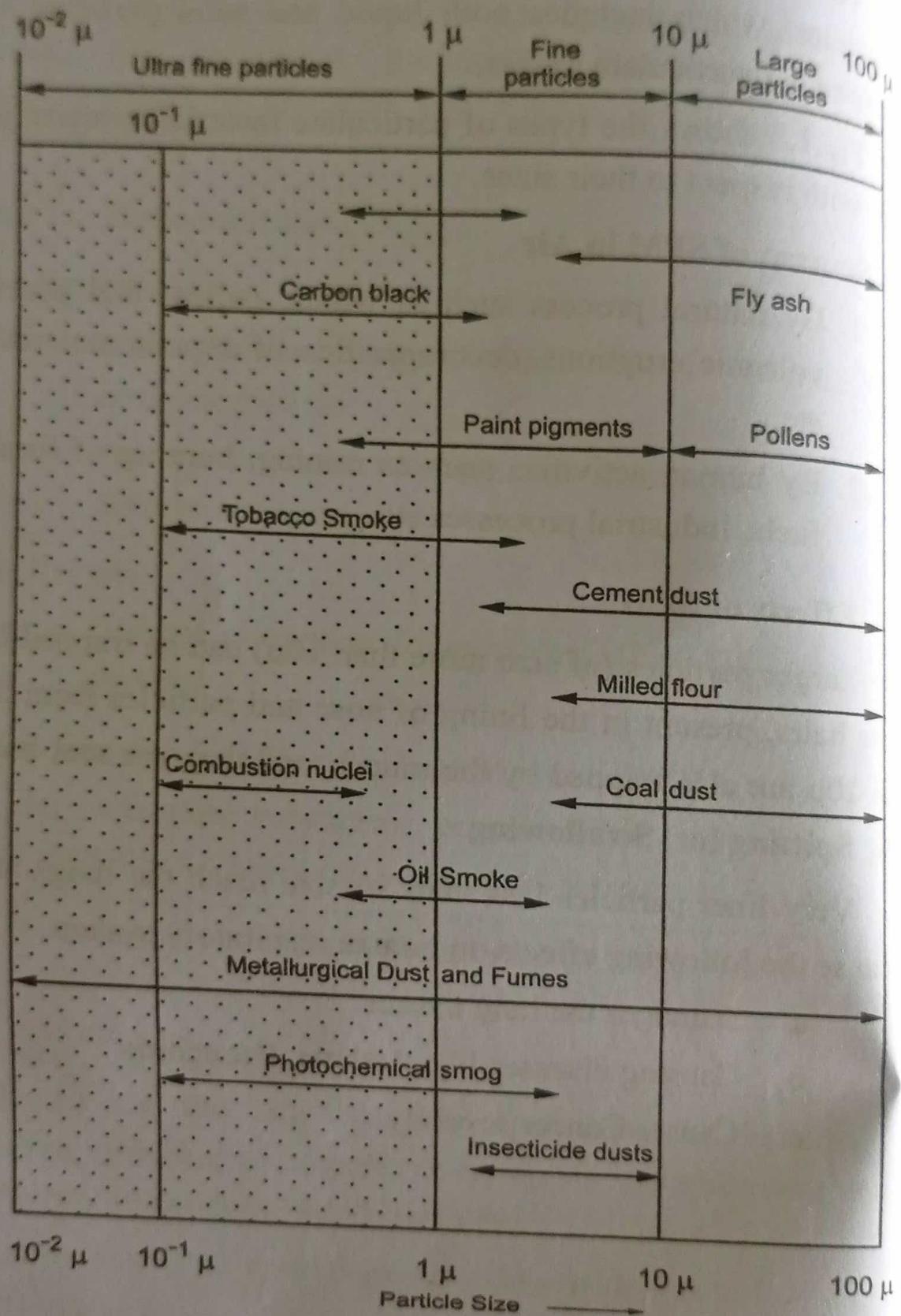


Fig. 1.3. SPM in air (based on sizes)

Smaller particles having size upto 10μ in size are called **Respiratory Suspended Particulate Matters (RSPM)**, (or) **PM10**. Smaller particles of sizes upto 2.5μ are called **PM2.5**.

As per the latest **Ambient Air Quality Standards** of India, the maximum annual concentrations of **PM10** and **PM2.5** are given as $60 \mu\text{g}/\text{m}^3$ and $40 \mu\text{g}/\text{m}^3$ respectively.

Some microscopic particulate materials, present in air, cause allergic reactions in, sensitive human bodies are called **allergic agents**. **Sneezing** is one of the **symptoms of allergy** followed by skin troubles and Bronchitis, Asthma etc.

1.6.6. Lead

It is another important air pollutant, emitted by all automobile vehicles. As per the **Indian Air Quality Standard**, the maximum of $0.5 \mu\text{g}/\text{m}^3$ is permitted as an annual concentration of lead in air.

Test for Lead

1. ED – XRF (using Teflon filter Method)
2. AAS/ICP Method.

1.6.7. Other Important Pollutants

Smoke

It is the resultant of incomplete combustion of carbonaceous materials such as coal, oil, tar and tobacco.

It consists of carbon particles less than $0.1\mu\text{m}$ in diameter. **Smoke** may be **condensation aerosol** with solid or solid and liquid particles.

Fog

Fog is an aerosol of liquid droplets near the grounds as distinct from clouds.

Fumes

Fumes are the solid particles generated by condensation from the gaseous state, generally after volatilization from molten metals etc. and often accompanied by a chemical reaction such as oxidation. Fumes are generally flocculating particles.

Mists

Mists are suspended liquid droplets generated by condensation from the gaseous to the liquid state or solid state by breaking up a liquid, into a dispersed state (such as splashing and atomizing). It may be called as liquid particle aerosol of any size or any origin.

Gases

Gases are defined as the formless, less dense, floating substances occupy the space of enclosure. They can be changed to the liquid or solid state only by the combined effect of increased pressure and decreased temperature. Gases can be diffused.

Vapours

They are the gaseous form of substances and can also be changed to liquid or solid states either by increasing the pressure and decreasing the temperature alone.

Aerosols

Aerosols are the air (or gas) suspensions of solids or liquid particles usually less than $50\mu\text{m}$ in diameter. Aerosols seldom occur as a single chemical species and may be physically complex as well.

For example, water droplets usually contain dissolved materials while solid aerosols contain absorbed gases.

Smog - Smog is the mixture of smoke and fog.

Haze - Haze is a suspension of small particles in the air which makes distinct large objects indistinct.

Smaze - Smaze is a mixture of haze and smoke.

Radio-Activity - The nuclear disintegrations of atoms undergo in giving off ionizing radiations.

Noise - Noise is an unwanted sound.

1.7. PHYSICAL EFFECT OF AIR POLLUTION

Decrease in visibility is the important and immediate effect of air pollution. The frequency of fog is increased in polluted areas. The physical effects of air pollutants can be classified as follows.

- a. Effects on Visibility
- b. Effects on urban atmosphere and climatic changes
- c. Effects on atmospheric constituents.

1.7.1. Effects on Visibility

Visibility depends on the transmission of light through the atmosphere and the capacity of eye to differentiate the object. Visibility can be reduced due to the pollutants in air depends on the following factors.

1. Size, concentration and physical characteristics of particulate matter
2. Nature of particulate matter in ambient air
3. Volume of air into which it gets mixed up

1.7.2. Effects on Urban Atmospheric and Weather Conditions

Urban air pollution may cause due to smoke, dust and other aerosols. Due to air pollution the solar radiation is reduced by 36%.

1.7.3. Effects of Atmospheric Constituents

The main source of the organic carbon in the bio-sphere is atmospheric CO₂. Due to combustion of fuels, the atmospheric CO₂ is increasing rapidly in the recent years. CO₂ causes the following effect.

- a. CO₂ increases the ambient temperature.
- b. CO₂ increases the Infra-red absorption.
- c. CO₂ increases the Green House effect.

1.8. EFFECT OF AIR POLLUTION

1.8.1. Effects of Air Pollution on Human Health

Particles of size smaller than 5 μ can penetrate to the human lungs and is deposited. Each pollutant affects the human body differently.

The following table 1.3 shows the various effects of air pollution on human health.

When computer monitors and other electronics are burned, they create cancer-producing dioxins and are released into the air.

Table 1.3. Various Effects of Air Pollution on Health

Sl.No	Air Pollutant	Properties	Important Sources	Effects on human health
1.	SO ₂ (Sulphur-di-Oxide)	Colour less gas	1. Combustion of fuels in automobile and power stations	<ul style="list-style-type: none"> 1. Breathing Problems Respiratory illness Lung diseases and death. 2. Astham Problem 3. Elderly people and children are greatly affected by SO₂
2.	(Carbon Monoxide) CO	Colour less taste less; odourless gas	1. Incomplete combustion of fuels and coal	<ul style="list-style-type: none"> 1. Cardio-Vascular diseases (due to the reduction of O₂ in tissues) 2. Visual perception Manual dexterity, Mental disability 3. Creates headaches 4. Formation of photochemical smog

Sl.No	Air Pollutant	Properties	Important Sources	Effects on human health
3.	Nitrogen oxides (NO_x) (NO etc)	1. Reddish Brown gas 2. Highly Reactive	1. Thermal power stations. 2. Combustion of fuels at high temperature.	1. Formation of Ozone 2. NO_2 creates the irritation in nose and lungs. 3. Increases the possibility for viral attacks.
4.	Carbon-Dioxide CO_2	Colour less gas	Combustion of coal, diesel and petrol.	1. Climatic changes 2. Global warming 3. Green house effect
5.	Suspended Particulate Matter	1. Solid particles (Dust, Smoke, Fumes, Etc) 2. Liquid Particles (Mist and Fog)	1. Smoker from Various agencies 2. Burning of garbage 3. Other burnings.	1. Breathing effects 2. Cardio-Vascular diseases. 3. Lung diseases. 4. Affects the elderly people and children.

Sl.No	Air Pollutant	Properties	Important Sources	Effects on human health
6.	Lead (Heavy Metal)	1. Colourless vapour	1. Leaded petrol in automobiles. 2. Consumed with the food, water, soil or dust.	1. Mental retardation 2. Behavioural disorders 3. Increases blood pressure 4. Heart diseases
7.	Ozone (O_3)	Colour less gas	1. Secondary pollutant produced by photo chemical pollution	1. Reduces lung functions 2. Creates cough sneezing, chest pain 3. Affects respiratory system
8.	Nuclear Wastes	Invisible Radio- active emissions.	1. Nuclear Weapon Testing 2. Nuclear power plants	1. Cancer 2. Mutations, deaths.

1.8.2. Effects of Air-Pollution on Plants

The important effect pollutant causes severe effect on plant is **fluorine**. Fluorine is mixed with air from the following ways.

1. Manufacturing process of Aluminium, Glass and Phosphate fertilizers
2. Clay baking operations

Effects

1. Concentration of fluorine in excess of about $0.3 \mu\text{g}/\text{m}^3$ cause **photo-toxicological effect** on plants.
2. Reduces the yield of a crop (or Plant).
3. Reduces the **photo-synthesis** of plants.
4. Reduces the quantities and nutrients present in the vegetables, fruit etc.
5. Creates very harmful effect on animals and human health, using the affected plants.

1.8.3. Effects of Air Pollution on Animals

When animals eat the air polluted plants, grasses and other vegetation, it will be highly affected. The important pollutants affect the animals are,

- a. Fluorine
- b. Arsenic
- c. Lead

The above pollutants affect the animals either from the industries situated nearby (or) from dusting and spraying.

1. The fluorine affects the animals in the following ways
 - a. Reduced milk production

- b. Lack of appetite
 - c. General ill-health
 - d. Reduced fertility
 - e. Growth reduction etc.
2. Arsenic creates **Arsenic poisoning** on animals with effective symptoms of thirst, vomiting uneasiness, irregular pulse and irregular respiration.
 3. Lead is a major air pollutant, creates harmful effect on animals, which are emitted from coal based industries (such as smelters) coke ovens etc. It creates **Lead Poisoning** on animals.

The various symptoms of lead poisoning on animals are,

- a. Inability to stand and staggering
- b. Prostration
- c. Paralysis of digestive tract
- d. Diarrhoea

1.8.4. Effects of Air-Pollution on Materials and Services

Air pollution affects various materials and services in the following ways.

- a. Corrosion
- b. Chemicals attack (direct and indirect)
- c. Abrasion
- d. Deposition and removal

In urban areas, air pollution causes severe economic losses by wastage of materials. The atmospheric deterioration of

materials is caused due to moisture, temperature, sunlight and air movement.

The following table 1.4 shows the effects of air pollution on various materials.

Table 1.4. Effects of Air Pollution on Materials

Sl. No	Air Pollutant	Other Factors	Materials	Effects
1.	SO ₂ , Acids and gases	With moisture	Building Materials	Colour deformation
2.	SO ₂ , Acids and gases	With moisture and temperature	Building Materials	1. Tamishing of surface 2. Losses of metal
3.	Sulphur Oxides, acids, gases	With moisture and sunlight	Textiles	1. Reduction in tensile strength
4.	Oxidants	With sunlight	Rubber	1. Reduction in tensile strength
5.	SO ₂ , H ₂ S and SPM	With Sunlight and moisture, fungus	Paints	1. Cracking 2. Colour Deformation

Sl. No	Air Pollutant	Other Factors	Materials	Effects
6.	SO ₂ , Acids and gases	With Sunlight and moisture	Paper	Embrittlement

1.8.5. Effects of Air Pollution on Aquatic Life

Atmospheric gas pollutants such as Carbon-Monoxide (CO), Carbon-di-Oxide (CO₂), Sulphur Oxides (like SO₂) and Nitrogen Oxides (NO_x) react with rain and forms acidic rain (called **acid rain**) affects fresh water bodies and the aquatic life (especially fishes) in the water bodies.

1.8.6. Economic Effect of Air Pollution

Various economic effects of air pollution are enlisted below.

1. Wastage of fuel through improper combustion in automobiles.
2. Vegetation and planting are also damaged due to various pollutants such as smog, dust etc. and hence the economic development of a country also get reduced.
3. Air pollutants cause the non-repairable damages to the art-treasures of a country. **TajMahal**, the **Colosseum in Rome**, the **San Marco Basilica in Venice** have shown signs of decay and deterioration due to the severe effect of air pollution.

4. Electronic industry is also affected severely due to the air pollution. The low-power electrical conduits (such as microamperes, milli-volts used) in electrical devices are sensitive with air pollution, developing thin insulating film resulting in open circuits and malfunctioning of the equipment.
5. Paper industry is also affected by air pollution problems. Books and writing paper become brittle and difficult to fold, when 2 to 9 ppm concentration of SO_2 acts for a period of 10 days.
6. Clothes, curtains and other textile materials are highly spoiled due to smoke, dust and sulphuric acid-mist. These increase the additional cost on laundry and dry cleaning.
7. Additional lighting is required to improve the visibility, where the poor visibility created by smog.
8. Glass materials and ceramic materials are highly affected due to air pollution, when they are exposed to atmosphere and moisture, and produce surface degradation.
9. Effect of buildings and building components due to the air pollution is an important aspect because the buildings and constructions are the big economical flow of a country. Increased cost for repairing and repainting for walls is the worst effect of air pollution on buildings
10. Leather industries and rubber tyred wheels are get cracked because of the continued contact the atmospheric pollutants.

1.8.7. Effects of Nuclear Power Reactors

Nuclear reactors do not produce air pollution or carbon dioxide while operating. However, the processes for mining and refining Uranium ore and making reactor fuel all require large amounts of energy. Nuclear power plants also have large amounts of metal and concrete, which require large amounts of energy to manufacture. If fossil fuels are used for mining and refining uranium ore, or if fossil fuels are used when constructing the nuclear power plant, then the emissions from burning those fuels could be associated with the electricity that nuclear power plants generate.

Generally, Nuclear Wastes from Radio-active emissions may create cancer in humans and sometimes mutations and deaths also, during Nuclear Weapon Testing and Nuclear power plants operations. However Nuclear Plants are operated in a controlled manner and hence the possibility of health hazards can be avoided.

1.8.8. Global Environmental Issues - Effects of Air Pollution

Following are the three major environment issues by various air pollutants.

Air pollution is an international issue because the pollutant created in a location affects not only the places nearby, but also affects the entire environment throughout the world.

1. Acid Rains
2. Ozone Depletion (and Ozone Hole)
3. Global Warming

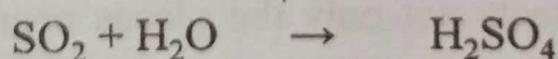
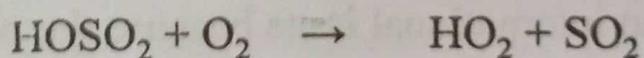
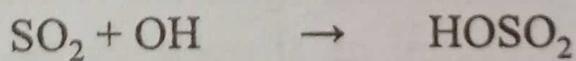
I. Acid Rain

Acid rain is defined as the rain having pH value equal to or less than 5.6, having harmful effects on humans, animals, plants, aquatics and infrastructures.

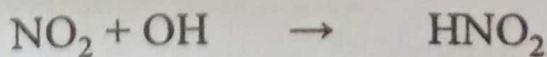
Generally the normal, clean rain fall having a pH value of about 6.9 (little acidic), when the atmosphere is free. This little acidic is due to the presence of natural carbon-di-oxide and Nitrogen oxides, which are the acid forming gases.

When the concentration of SO_x, NO_x and CO₂ increases in the atmosphere, the rain water become more acidic, sometimes it may even be less than pH of 5 or 4. The acidity in the rain water is formed due to the chemical formation of Nitric Acids (HNO₃), Sulphuric Acids (H₂SO₄) and Sulphurous Acids (H₂SO₂) from the oxides of Nitrogen and Sulphur.

The primary pollutant which causes 2/3 of the acid rain is SO₂. SO₂ is produced by the burning of coals and oils largely used for generation of heat and power in industries and domestic uses. Also, SO₂ is emitted from the large usage of petrol and diesel in automobiles.



Nitrogen oxides like NO₂, NO₃ and N₂O₂ are other important pollutant which causes 1/3 of the total acidic rain. NO_x are generally produced from emissions of automobiles, nitrogenous fertilizers, forest fires, grass lands etc.



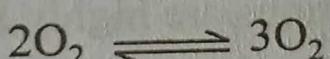
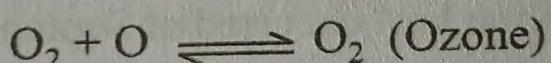
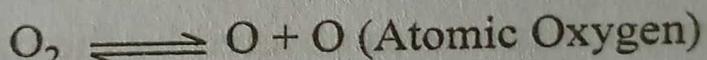
The other (but very little) pollutant which causes acid rain is HCl. Emissions from the industries may contain HCl, which causes acidity to the rain, but this is very little when comparing with other pollutants.

Acid rain has been shown to have adverse impacts including **heart and lung problems, Asthma and Bronchitis**. It also affects forests, freshwaters, aquatic animals and soils.

II. Ozone Depletion

The reduction of thickness of Ozone layer due to the attack of chemical pollutants is called **Ozone Layer Depletion**.

Ozone is formed from the molecular and atomic oxygen, as follows,



The ultra- violet radiations are highly harmful to all kinds of life on Earth. If the UV rays are not filtered by the ozone layer, it creates several impacts on humans, animals and plants on the planet Earth. The highest problem due to the UV radiation is to cause mutation in **DNA**, forming **skin cancers**, including deadly **Melanoma**.

A 10% overall depletion of ozone is estimated to cause 26% increase in the **non-melanoma skin cancers**, throughout the world.

Causes of Ozone Depletion

Following are the reasons for ozone layer depletion in the stratosphere.

- a. Use of Chloro-Fluro Carbons (CFCs)
- b. Nuclear Tests
- c. Supersonic Transport, Rockets and space shuttles
- d. Nitrogenous fertilizers

Ozone Hole is defined as the ozone depletion and in which the thickness of the ozone layer at the Stratosphere is less than 150 DU, (Dobson Unit) represent the shortage of ozone and permits the UV radiation may enter to atmosphere and reach the earth through these regions.

$$1 \text{ DU} = 0.01 \text{ mm}$$

The maximum area covered by the ozone hole was found to be about 30 million km² occurred at September 2000.

The ultra- Violet radiations are highly harmful to all kinds of life on Earth. If the UV rays are not filtered by the ozone layer, it creates several impacts on humans, animals and plants on the planet Earth. The highest problem due to the UV radiation is to cause mutation in DNA, forming skin cancers, including deadly **Melanoma**.

III. Global Warming

Global warming is the increase of Earth's average surface temperature, due to the effect of green-house gases (such as CO₂) emissions from burning of fossil fuels or from deforestation. Global warming is the type of greenhouse effect.

The climate of the earth is mostly influenced by the first 10 to 12 km from the earth surface. If the earth is viewed from the space, the climate layer of the atmosphere would be a thin layer as thick as the skin on an onion.

During the past few years, Earth's climate has been changed to be getting hotter and hotter, year after year.

Green House Gases in the troposphere layer of the atmosphere act like the glass of a green house, trapping some of the heat, as it radiates back from the Earth into the space.

Earth is surrounded by a gaseous cover and the atmosphere provides oxygen to the living, maintains the heat balance of the earth and protects the livings from the harmful radiations. Low length radiation coming from sun is reflected back in the form of IR long reflected, but part of it is intercepted by gases in the atmosphere and in turn provides heat on Earth to keep it warm.

Green-house gases act like a glass in the green house trapping some of the heat as it radiates back from the Earth to the atmosphere.

The gases, which cause global warming (or climatic changes) by green-house effect, are called **Green House Gases**.

1. Carbon-di-oxide (CO_2)
2. Methane (CH_4)
3. Nitrogen oxides (NO_x)
4. Chloro-Fluro Carbons (CFCs)

5. Ozone (O_3)

6. Water Vapours

The **Greenhouse Effect** is a natural process that increases the temperature of the Earth's surface, which is caused by conversion of solar radiation into heat.

When the heat energy reaches the Earth's atmosphere, some of it is reflected back to space and the rest is absorbed and re-radiated by greenhouse gases. It is the process by which radiation from a planet's atmosphere warms the earth's surface to a temperature above what it would be without its atmosphere.

Greenhouse effect is the increase in the Earth's average lower atmosphere temperature (near surface) due to heat retention caused by the accumulation of greenhouse gases (including water vapour, carbon dioxide, methane, nitrous oxides and chlorofluorocarbons or CFCs).

1.9. AIR QUALITY STANDARDS

Air quality standards are defined as the standard limits, placed on the levels of air pollution in the ambient air, during a given period of time.

Air quality standards define the permissible level of a pollutant (or type of pollutants) in the atmosphere. These are the expressions of public policy and that the requirements for further action.

Air quality standards are not only based on the quality of air, but also based on the economic, social, technical and political factors.

1.9.1. Objectives of Air Quality Standards

Following are the objectives of air quality standards. Air quality standards are necessary to,

- ✓ Assess current or historical air quality
- ✓ Guide decisions on the permitting of new or modified facilities
- ✓ Guide decisions on episode management, such as air quality advisories
- ✓ Develop long-term air-management strategies and evaluate progress, and
- ✓ Aid regulatory development.

1.9.2. Steps in Air Quality Standards

Following steps are adopted in the development of air quality standards.

1. Prepare the air quality criteria, which indicate the relationship between the pollutant concentrations in the air and its effects on the air. This is called as ‘Guide’.
2. Develop the quality goals from the quality criteria, which are the concentrations of pollutants.
3. Develop the quality standards from the air quality criteria.
4. In order to develop the above standards, there must be standard for measurement and testing of the ambient air and air pollution effects.

Complete elimination of air pollution is not practically possible and some level of pollutants may be permitted in the atmosphere.

The standard about the permissible level of air pollutants, maintained in the atmospheric air is called 'air quality standards'.

Air quality standards are described by,

1. Ambient Air Quality Standards
2. Other Air Quality Standards

1.9.3. Ambient Air Quality Standards

Ambient air quality standards are defined as the legal limits, placed on the concentration of air pollutants in a community, where the people and things are exposed.

The first ambient air quality standards were adopted in 1982 by the **Central Pollution Control Board (CPCB)** and revised in 1994 and again in 2009.

Various agencies responsible for air quality standards are **Central Pollution Control Board (CPCB)** and **State Pollution Control Boards (SPCBs)**.

All of the **Central and State Pollution Control Boards** are functioning under the control of the **Ministry of Environment and Forest (MoEF)**.

The CPCB, working with the SPCBs, provides technical advice to MoEF, in order to achieve the objectives formed in the **Air Act, 1981**. SPCBs can set more standards than the existing national standards in their respective states.

Table 1.5.

NATIONAL AMBIENT AIR QUALITY STANDARDS (as of 2009)					
Sl. No	Pollutants (In $\mu\text{g}/\text{m}^3$)	Time Weighted Average	Concentration in Ambient Air (Industrial, Residential, Rural and Other Areas)		
			Pollut ants (In $\mu\text{g}/$ m^3)	Time Weighted Average	Methods of Measurement
1.	Sulphur Di oxide (SO_2)	Annual *	50	20	Improved West and Gaeke Ultraviolet Fluorescence
		24 Hours**	80	80	
2.	Nitrogen Dioxide (NO_2)	Annual *	40	30	Modified Jacob & Hochheiser (Na – Arsenite) Chemiluminescen ce
		24 Hours **	80	80	
3.	Particulate Matters (Size less than $10\mu\text{m}$) or PM10	Annual *	60	60	Gravimetric TEOM Beta attenuation
		24 Hours **	100	100	
4.	Particulate Matter (Size less than $2.5\mu\text{m}$) or PM2.5	Annual *	40	40	Gravimetric TEOM Beta attenuation
		24 Hours **	60	60	

5.	Ozone (O_2)	8 Hours	100	100	UV Photometric Chemiluminescence Chemical Method
		* 1 Hour	180	180	
		**			
6.	Lead (Pb)	Annual *	0.50	0.50	AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper ED-XRF using Teflon filter
		24 Hours	1.0	1.0	
		**			
7.	Carbon Monoxide (CO)	8 Hours **	02	02	Non dispersive Infrared (NDIR) Spectroscopy
		1 Hour **	04	04	
8.	Ammonia (NH_3)	Annual *	100	100	Chemiluminescence - Indophenol blue method
		24 Hours	400	400	
		**			
9.	Benzene (C_6H_6)	Annual *	05	05	Gas Chromatography (GC) based continuous analyzer Adsorption and desorption followed by GC analysis
10.	Benzopyrene (BaP) Particulate phase only, ng/m^3	Annual *	01	01	Solvent extraction followed by HPLC/GC analysis

11.	Arsenic (As), ng/m ³	Annual *	06	06	AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
12.	Nickel (Ni), ng/m ³	Annual *	20	20	AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper

* Annual Time Weighted Average (ATA) is the Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigations.

1.9.4. Other Air Quality Standards

The other air quality standards are,

- (a) Point of Impingement Standards
- (b) Soiling Index
- (c) Odour Standards

- (d) Visibility Standards
- (e) Standards for Particulate Matter Deposited etc.
- (a) Point of Impingement Standards

Point of impingement standards (or Quasi-Emission Standards) are the limits on **Specific Pollutants** on the ambient air at the ground level required by the National, State or local regulations to be used in diffusion computations to determine the limits of emission from specific sources.

(b) Soiling Index

Soiling index is the measurement of transmitted (or reflected) light or from a spot of particulate matter collected on a filter for a defined period of time.

1.10. EMISSION STANDARDS

1.10.1. Emission Standards

Emission Standards are the limits, establish the permitted levels of emission from the specific groups of emitters and require that all members of these groups emit, not more than these permitted emission levels.

The emission standards are applicable to all national, regional and local emitters. Emission standards are completed based on the air quality standards.

Emission Standards are generally designed to achieve air quality standards and to protect human life.

Emission intensity (also carbon intensity, C.I.) is the emission rate of a given pollutant relative to the intensity of a specific activity, or an industrial production process. Emission intensities are used to derive estimates of air

pollutant or greenhouse gas emissions based on the amount of fuel combusted, the number of animals in animal husbandry, on industrial production levels, distances traveled or similar activity data.

Emission standards are of two types.

- (i) Emission standards for mobile sources
- (ii) Emission standards for stationary sources

(i) Emission Standards for Mobile Sources

Mobile sources include ships, aircraft, automobile and locomotives in the railroads. Once air quality standards are established, such standards can be used as the basis for formulating the emission standards. Hence, the emission standards represent the emission levels not be exceeded, if air quality goals are to be achieved.

Bharat Stage Emission Standards are emission standards instituted by the **Government of India** to regulate the output of air pollutants from internal combustion engine equipment, including motor vehicles. The standards and the timeline for implementation are set by the CPCB under the MoEF.

The standards, based on European regulations were first introduced in 2000. Progressively stringent norms have been rolled out since then. All new vehicles manufactured after the implementation of the norms have to be compliant with the regulations. As of 2014, the country is under a combination of Euro 3 and Euro 4-based norms. Euro 6 norms are planned to be introduced across the country by the April 1, 2020.

Emission standards have been adopted for the following categories of new engines and/or vehicles:

- ✓ Cars and Light Trucks - Emissions
- ✓ Cars and Light Trucks - Fuel Economy
- ✓ 2- and 3-Wheel Vehicles
- ✓ Heavy-Duty Truck and Bus Engines
- ✓ Non-Road (Off-Road) Diesel Engines
- ✓ Generator Sets

(ii) Emission Standards for Stationary Sources

Stationary sources include the sources except all other mobile sources. These standards relating to the stationary site, process, stack, chimney or vent intended to achieve the desired air quality. The emission standards also include the standards for buffer zones, stack height, design of the equipment, fuel composition, etc.

Emission Standards may be derived from,

- (i) Process and Equipment Considerations
- (ii) Air Quality Considerations and
- (iii) Both the above

1.10.2. Emission Standards by Air Act (1981)

Section 17(1) (g) of the Act, empowers the **State Board** to lay down, in consultation with the **Central Board** and having regard to the standards for the quality of air laid down by the **Central board**.

This section also provides for laying down different standards for emission for different industrial plants

considering the quantity and the composition of the emissions of air pollutant into the atmosphere from these industrial plants.

It is identified that there are two types of limits on emissions from major polluting scheduled industries, which are,

1. **Standards laid down** under section 17(1)(g) and applicable over the entire state which the industry concerned will have to comply with, wherever it might be located.
2. **Specific emission limits** that may be prescribed by the pollution control boards in the concerned conditions under section 21 (5). These limits should generally be more stringent than the standards set under section 17(1) (g).

1.10.3. Main functions of the Central Pollution Control Board (CPCB)

The Air (Prevention and Control of Pollution) Act, 1981 describes the main functions of the Central Pollution Control Board (CPCB) as follows.

- ♣ To advise the Central Government on any matter concerning the improvement of the quality of the air and the prevention, control and abatement of air pollution.
- ♣ To plan and cause to be executed a nation-wide programme for the prevention, control and abatement of air pollution.

- ◆ To provide technical assistance and guidance to the State Pollution Control Board.
- ◆ To carry out and sponsor investigations and research related to prevention, control and abatement of air pollution.
- ◆ To collect, compile and publish technical and statistical data related to air pollution; and
- ◆ To lay down and annul standards for the quality of air

The mandate provided to the CPCB under the Air (Prevention and Control of Pollution) Act empowers it to set standards for the quality of air.

1.10.4. Industries Specified in the Schedule

Various industries enlisted in the schedule under the Air Act (1981), are as follows.

1. Asbestos and asbestos products industries
2. Cement and cement products industries
3. Ceramic and ceramic products industries
4. Chemical and Allied industries
5. Coal and lignite-based chemical industries
6. Engineering industries
7. Ferrous metallurgical industries
8. Fertilizer industries
9. Foundries
10. Food and Agricultural Products industries
11. Mining industry
12. Non-Ferrous metallurgical industries

13. Ores/Mineral Processing industries including beneficiation, pelletization, etc.
14. Power (coal, petroleum and their products) generating plants and boiler plants
15. Paper and pulp (including paper products) industries
16. Textile processing industry (made wholly or in part of cotton)
17. Petroleum refineries
18. Petroleum products and petro-chemical industries
19. Plants for recovery from and disposal of wastes
20. Incinerators

1.10.5. Permissible Process Emission Standards for Specific Substances

Table 1.6. Permissible Process-Emission Standards for Specific Substances

Substance	Maximum Permissible Concentration, ppm
Chlorine	5
Benzyl chloride	5
Bromine	0.5
Fluorine	0.5
Mercaptans	0.5
Phosgene	0.5
Phosphorus trichloride	2.5
Sulphur monochloride	5
Sulphur pentafluoride	0.1
Acetic anhydride	25

Aniline	25
Cresol	15
Dimethyl amine	30
Trimethyl amine	0.5
Total amines	1
Dimethyl sulphide	0.1
Ethanolamine	10
Formaldehyde	10
Vinyl chloride	500
Ethylene dichloride	150
Formic acid	15
Hydrazine	3
Hydrogen bromide	10
Hydrogen chloride	25
Hydrogen fluoride	10
Hydrogen sulphide	25
Hydrogen cyanide	10
Nitric acid	10
Nitrogen oxides	15
Pyridine	10
Hydrocarbons	25
Sulphur dioxide	15
Acetic acid	50
Ammonia	250
Benzene	30
Carbon-di-sulphide	50
Carbon tetrachloride	30

Standards for Minimum Stack Height

Due to an effective dispersion and dilution of pollutants in the atmosphere, the maximum ground level concentration will be less for the tallest stack or chimney. The minimum stack height to be provided in an industry is given in table 1.7.

Table 1.7. Guide Lines for Minimum Stack Height (H_{min})

Sl. No	Plants	H_{min} (m)
1.	For Thermal power plants, releasing q kg / hour of SO_x emissions per hour	
Boiler Size		
	Less than 200MW	$14 Q^{0.3}$
	200MW to 500MW	220
	500MW and more	275
2.	For particulate emission rate of Q_1 tonnes/ hour	$74 Q_1^{0.27}$
3.	For all plants (Except thermal power plants)	30

Note If the stack height arrived at by using the above criteria are different, then the higher value should be taken as the minimum stack height. However, in no case should the height of the stack be less than 30 m.

Table 1.8. Stack Gas Emission Standards

Sl. No	Industry	Standard for particulate matter emission		
		Capacity	Protected Area	Other Area
1.	Cement Industry	200 tpd and less	250 mg/Nm ³	400 mg/Nm ³ ×
		Greater than 200 tpd	150 mg/Nm ³	250 mg/Nm ³
2.	Thermal Power Plants	Boiler size	Protected Area	Other Area
			Old - Before 1979	New - After 1979
		< 200 MW	150 mg/Nm ³	600 mg/Nm ³
		> 200 MW	150 mg/Nm ³	600 mg/Nm ³

3. Iron and Steel Manufacturing		Process	Emission limits for particulates
Sintering plant			150 mg/Nm ³
Coke oven		-	
Blast furnace		-	
Steel Making-during normal operation		150 mg/Nm ³	
During oxygen lancing		150 mg/Nm ³	
Fertilizer (Urea) Industry		Standard for particulate matter emission from prilling tower is 50 mg/Nm ³	
Nitric Acid Manufacturing		Standard for oxides of nitrogen is 3 kg of NO per tonne of weak acid (before concentration) produced	

6. Sulphuric Acid Manufacturing	Process	Standard for sulphur dioxide and acid mist emission	
		Sulphur dioxide emission	Acid mist emission
Single Conversion - Single Absorption	10 kg/tonne of concentrated (100%) acid produced	50 mg/Nm ³	
Double Conversion - Double Absorption	4 kg tonne of concentrated (100%) acid produced	50 mg/Nm ³	
7. Calcium Carbide Industry	Source	Emission limit for particulates	
	Kiln	250 mg/Nm ³	
	Arc furnace	150 mg/Nm ³	

8.	Copper, Lead and Zinc Smelting	Source	Emission limit for particulates
		Concentrator	150 mg/Nm ³
		Smelter and converter	Off-gases must go for H ₂ SO ₄ manufacturing No release of SO ₂ /SO ₃ shall be permitted from the smelter or converter.
9.	Carbon Black		Standard for particulate matter emission is 150 mg/Nm ³
10.	Fertilizer (Phosphatic) Industry	Process	Emission
		Acidification of rock phosphate	25 mg/Nm ³ as total fluoride (F-)
		Granulation, mixing, rock grinding	150 mg/Nm ³ of particulate matter from each process.

TWO MARKS QUESTIONS AND ANSWERS

1. Define air pollution. *(Nov/Dec 2018)*

Air Pollution is defined as the pollution in the atmospheric air, due to the presence of solid, liquid, or gaseous material and causes the problems to humans, living systems, plants etc.

2. Differentiate Pollution and Pollutant.*(Nov/Dec 2015) (April/May 2017)*

Air Pollution is defined as the pollution in the atmospheric air, due to the presence of solid, liquid, or gaseous material and causes the problems to humans, living systems, plants etc.

A Pollutant is defined as a material (or substance) which creates the air pollution and in the form of liquid, gaseous or solid.

3. What are the layers of the atmosphere? *(Nov/Dec 2018)*

1. Troposphere (0 to 12 km)
2. Stratosphere (12 to 50 km)
3. Mesosphere (50 to 80 km)
4. Thermosphere (80 to 500 km)
5. Exosphere (above 500 km)

4. Why temperature decreases with increases in height?

Solar radiation is the main heat source and it is absorbed at the ground level and hence, the temperature decreases with increase in height of the troposphere.

5. What is planetary boundary layer?

(May/June 2013) (April/May 2017)

The planetary boundary layer is the part of the troposphere that is closest to Earth's surface and is directly affected by it, mainly through turbulent diffusion.

6. What are the sources of air pollution? (Nov/Dec 2016)

(Nov/Dec 2016, R-2008) (Nov/Dec 2017)

1. Natural Sources

2. Man-Made Sources

7. Mention the classification of air pollutants.

(May/June 2016)

1. Classification based on the origin.

(i) Primary Air Pollutants

(ii) Secondary Air Pollutants

2. Classification based on the chemical composition.

(i) Organic Compounds

(ii) In-Organic Compounds

3. Classification based on the state of matter.

(i) Particulate Pollutants

(ii) Gaseous pollutants.

8. Define primary air pollutants. Give examples.

(Nov/Dec 2011) (Nov/Dec 2017)

Pollutants, directly emitted from the identifiable sources are called **primary air pollutants**.

Ex: SO₂, CO, CO₂, NO, NO₂ etc.

- 9. What are secondary air pollutants? Give examples.**
(May/June 2012) (Nov/ Dec 2012) (May/June 2013)
(Nov/Dec 2011). (May/June 2016) (Nov/Dec 2017)

Primary pollutants react with one another or with water vapour in the presence of sunlight forms, a new form of pollutant, called **secondary pollutants**.

Ex: Sulphuric Acid (H_2SO_4), Ozone (O_3) etc.

- 10. Brief the effect of Carbon Monoxide on human being.**

(May/June 2012)

[OR]

How does Carbon Monoxide affect human health?

(Nov/Dec 2012)

[OR]

How does inhalation of carbon monoxide affect human health?

(Nov/Dec 2017)

Carbon monoxide has a greater blood-affinity property and which has been affected by **blood hemoglobin** 200 times more than O_2 .

This CO replaces the O_2 present in the hemoglobin and forms **Carboxy-hemoglobin**. (CO.Hb).

If the quantity of **Carboxy-hemoglobin** is less, it produces the little headache, reduction in reaction time etc. on human beings.

If the quantity of CO.Hb concentration is high, it creates difficulty in breathing, heart problems etc. Also, if CO.Hb quantity is about 50% of Hb, it makes death of human being.

11. What are the major effects of air pollutants on human health? *(April/May 2015)*

1. Effects on Visibility
2. Breathing Troubles
3. Increases Blood Pressure
4. Heart and Lung Diseases etc

12. Name any two effects on plants and also pollutant responsible. *(Nov/Dec 2014)*

1. Excess Fluorine ($0.3\mu\text{g}/\text{m}^3$) - Photo-toxicological effect.
2. Chemical pollutants - Yield reduction in Crops.

13. List two effects of air pollutants on materials.

(May/June 2016)

- a. Corrosion
- b. Chemicals attack (direct and indirect)
- c. Abrasion
- d. Deposition and removal

14. List out the various air pollution caused by nuclear energy program. *(Nov/Dec 2017)*

Nuclear wastes from Radio-active emissions may create cancer in humans and sometimes mutations and deaths also, during Nuclear Weapon Testing and Nuclear power plants operations.

15. Define Acid Rain.

Acid rain is defined as the rain having pH value equal to or less than 5.6, having harmful effects on humans, animals, plants, aquatics and infrastructures.

16. Define global warming.

(Nov/Dec 2018)

Global warming is the increase of Earth's average surface temperature, due to the effect of green-house gases (such as CO₂) emissions from burning of fossil fuels or from deforestation. Global warming is the type of greenhouse effect.

17. Write the effects of Ozone Depletion. (May/June 2014)

The ultra- Violet radiations are highly harmful to all kinds of life on Earth. If the UV rays are not filtered by the ozone layer, it creates several impacts on humans, animals and plants on the planet Earth. The highest problem due to the UV radiation is to cause mutation in DNA, forming skin cancers, including deadly Melanoma.

18. Define 'Ozone Hole'.

Ozone Hole is defined as the ozone depletion and in which the thickness of the ozone layer at the ozone layer is less than 150 DU, represent the shortage of ozone and represents the UV radiation may enter to atmosphere and reach the earth through these regions.

19. List out air pollutants responsible for ozone layer depletion.

(Nov/Dec 2014)

- a. Use of Chloro-Fluro Carbons (CFCs)

- b. Nuclear Tests
- c. Supersonic Transport, Rockets and space shuttles
- d. Nitrogenous fertilizers

20. *What is green-house effect?* (April/May 2015)

The **Greenhouse Effect** is a natural process that increases the temperature of the Earth's surface, which is caused by conversion of solar radiation into heat.

21. *What are the principal gases of concern in green-house effect? (April/May 2015) or*

What are green-house gases?

1. Carbon-di-oxide (CO_2)
2. Methane (CH_4)
3. Nitrogen oxides (NO_x)
4. Chloro-Fluro Carbons (CFCs)
5. Ozone (O_3)
6. Water Vapours

22. *What are Air Quality Standards?*

(Nov/ Dec 2012) (May/June 2013)

Air quality standards are defined as the standard limits, placed on the levels of air pollution in the ambient air, during a given period of time.

23. *Explain briefly the various air quality standards.*

(Nov/Dec 2016)

1. Ambient Air Quality Standards
2. Other Air Quality Standards
 - ✓ Point of Impingement Standards

- ✓ Soiling Index
- ✓ Odour Standards
- ✓ Visibility Standards
- ✓ Standards for Particulate Matter Deposited etc.

24. List the air quality standards for residence zone.

(Nov/Dec 2015)

Refer Table 1.5 Page 1.47

25. What are the Emission Standards?

(May/June 2012) (Nov/Dec 2017)

Emission Standards are the limits, establish the permitted levels of emission from the specific groups of emitters and require that all members of these groups emit, not more than these permitted emission levels.

26. Define Ambient Air Quality.

(May/June 2014)

Ambient air quality standards are defined as the legal limits, placed on the concentration of air pollutants in a community, where the people and things are exposed.

REVIEW QUESTIONS

1. Explain the elements of the atmosphere. (8)

(Nov/Dec 2018)

Refer Chapter 1.2.3. Page 1.10

2. Give a detailed account on sources and classification of air pollutants. (8) (Nov/Dec 2011) (8) (May/June 2012)

Refer Chapter 1.4. and 1.5 Page 1.15 and 1.18

3. Define air pollution and explain classification of air pollution with suitable examples. (16) (May/June 2014) (16) (Nov/Dec 2015) (16) (April/May 2017)

Refer Chapter 1.1 and 1.5 Page 1.1 and 1.18

4. Explain briefly about the various classification of air pollutants. (16) (Nov/Dec 2016)

Refer Chapter 1.5 Page 1.18

5. What are the various Secondary Air Pollutants? Discuss in detail. (Nov/Dec 2017)

Refer Chapter (II) 1.5.1. Page 1.18

6. Briefly discuss about the various types of gases causing air pollution. (16) (Nov/Dec 2017)

Refer Chapter 1.6 Page 1.20

7. List out the various health effects of polluted air on human beings and also corresponding air pollutant/pollutants. (8) (May/June 2013) (8) (Nov/Dec 2015) (May/June 2016) (8) (April/May 2017) (16) (Nov/Dec 2018)

Refer Chapter 1.8.1. Page 1.30

8. Explain the effects of CO, SO₂, and heavy metals on human being. (10) (Nov/Dec 2014)

Refer Chapter 1.8.1. Page 1.30

9. List out various air pollutants, their sources and its effect on both plant and human being. (May/June 2012) (May/June 2014) (16) (April/May 2018)

Refer Chapter 1.5, 1.4, 1.8.1. and 1.8.2. Page 1.18, 1.15, 1.30 and 1.34.

10. State the various classifications of particulates and explain their effects on Plants, Animals and Materials. (10) (April/May 2015)

Refer Chapter 1.8.2., 1.8.3 and 1.8.4 Page 1.34 and 1.35

11. Explain the effects of air pollution on plants.

(7) (May/June 2013)

Refer Chapter 1.8.2. Page 1.34

12. Discuss in detail about the health effects of various air pollutants on human beings and animals.

(Nov/Dec 2017)

Refer Chapter 1.8.1. and 1.8.3. Page 1.30 and 1.34

13. Describe in detail the effects of air pollution on human beings vegetation and animals. (16) (Nov/Dec 2016)

Refer Chapter 1.8.1., 1.82. and 1.8.3. Page 1.30 and 1.34

14. Discuss in detail about the effect of air pollution on plants and farm animals. (16) (Nov/Dec 2017)

Refer Chapter 1.8.2 and 1.8.3. Page 1.34

15. Explain the various effects of air pollution on materials. (8) (Nov/Dec 2018)

Refer Chapter 1.8.4. Page 1.35

16. How does air pollution bring economic impact on a country? (8) (Nov/Dec 2011) (8) (May/June 2012)

(8) (Nov/Dec 2012) (8) (Nov/ Dec 2012, R-2008)

Refer Chapter 1.8.6. Page 1.37

17. Explain the effect of air pollution in global scale. (8) (Nov/Dec 2012)

Refer Chapter 1.8.8. Page 1.39

18. What is global warming? How do GHG contribute to this? (8) (May/June 2012) (9) (May/June 2013)

(10) (Nov/Dec 2014)

Refer Chapter (III) 1.8.8. Page 1.39

19. What are the green house gases? Explain.

(8) (Nov/ Dec 2012)

Refer Chapter (III) 1.8.8. Page 1.39

20. Explain the causes of 'ozone layer depletion' with necessary equations. (8) (Nov/ Dec 2012)

Refer Chapter (II) 1.8.8. Page 1.41

21. Describe the effects of ozone layer depletion. (8) (Nov/Dec 2018)

Refer Chapter (II) 1.8.8. Page 1.41

22. Write short notes on ozone layer depletion and compounds responsible. (6) (April/May 2015)

Refer Chapter (II) 1.8.8. Page 1.41

23. Write the causes, of ozone layer depletion. (10) (May/June 2016)

Refer Chapter (II) 1.8.8. Page 1.41

24. What are ambient air quality standards? What are its objectives? (4) (May/June 2012) (8) (May/June 2014)

Refer Chapter 1.9.4. and 1.9.1. Page 1.49 and 1.44

25. Discuss in detail about the air quality standards of EPA and Indian Standards. (16) (Nov/Dec 2017)

Refer Chapter 1.9 Page 1.44

26. Explain briefly the various air quality standards. (16) (Nov/Dec 2016)

Refer Chapter 1.9 Page 1.44

27. Make a note on air quality standard for ambient air and for industrial exposure. (6) (Nov/Dec 2014)

Refer Chapter 1.9 Page 1.44

28. Explain air quality standards. (8) (April/May 2018)

Refer Chapter 1.9 Page 1.44

29. State and explain the goals of Air quality standards.

(8) (Nov/Dec 2011)

Refer Chapter 1.9.1. Page 1.45

30. What are air quality standards? How would this contribute to air quality management? (8) (Nov/Dec 2012)

Refer Chapter 1.9.2. Page 1.45

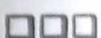
31. Discuss in detail about National Ambient Air Quality Standards for our Indian Cities. (Nov/Dec 2017)

Refer Table 1.5 Page 1.47

32. Write a short note on Emission standards

(8) (May/June 2014)

Refer Chapter 1.10. Page 1.50



UNIT - II

METEOROLOGY

Effects of meteorology on Air Pollution - Fundamentals, Atmospheric stability, Inversion, Wind profiles and stack plume patterns- Atmospheric Diffusion Theories – Dispersion models, Plume rise

2

METEOROLOGY

2.1. INTRODUCTION

Meteorology is the branch of science concerned with the processes and phenomena of the atmosphere, especially as a means of forecasting the weather.

The factors which change the concentration of air pollutants in a particular area are called **Meteorological Factors** of air pollution.

The concentration of air pollutants in a particular area from various sources depends highly on the local weather conditions.

2.1.1. Objectives of Meteorological Factor Study

The degree of air pollution may vary, even though the total emissions into the atmosphere in a given area remain same from day-to-day, due to changes in meteorological conditions. Meteorological data is very essential for air pollution studies.

Various objectives of studying the meteorological factors are as follows.

1. To identify the source of pollutants
2. To predict pollution events such as high concentration days

3. To simulate and to predict the air quality (using computer models)
4. To determine the stack height
5. To evaluate the intensity of air pollution etc.

2.1.2. Effects of Meteorology on Air Pollution

Meteorological factors are highly influencing the quantity of pollution in the earth's atmosphere from the following ways.

- ✓ Solar radiation and temperature affect the quantities of pollutant emitted, by their influence on the amount of space heating required.
- ✓ Sunshine is the reason for photochemical production of oxidants forming smog.
- ✓ The wind velocity, turbulence and stability affect the transport, dilution and dispersion of the pollutants.
- ✓ The rainfall has a scavenging effect in washing out (rainout) particles in the atmosphere.
- ✓ The humidity is a frequent and important factor in determining the effect that concentrations of pollutants have on property, vegetation and health.

In view of these effects, meteorologists are involved in the following aspects of air pollution control.

- 1) Forecasting air pollution potential, so that air pollution control agencies may alert industry to carry out temporary abatement action.
- 2) Selecting sites and designing emission systems for large industrial sources.

- 3) Establishing air monitoring surveys.
- 4) Carrying out research in air pollution control methods.

2.1.3. Meteorological Factors

The important meteorological parameters that influence air pollution can be classified as,

(a) Primary Parameters

1. Wind Speed and Direction
2. Temperature
3. Atmospheric Stability
4. Mixing Height

(b) Secondary Parameters

1. Rainfall and Precipitation
2. Humidity
3. Solar Radiation
4. Visibility

The meteorological factors highly depend on the latitude, season and the topography of the area.

I. Wind Speed and Direction

The speed and direction of wind changes the concentration of pollutants, especially near the ground levels. The high speed of wind carries away the pollutants at or near the point of emission.

The emitted air pollutants easily get diluted with high volume of atmospheric air. The speed of dilution process highly depends on the speed and direction of the wind.

Alternatively, when the wind speed is low, pollutants concentrate the area at or near the point of discharge.

Gustiness is an important characteristic of surface winds that determines the extent to which the pollutants are diluted and mixed with surrounding air. It is directly proportional to the wind speed.

The concentration of pollutants is inversely proportional to the wind speed.

In plain (or rough) terrain, the wind speed and direction near the source decide the subsequent movement of the pollutants.

In hilly terrain, hills may deflect the air flow either horizontally, vertically or both and the quantity of deflection depends on the vertical stability of the atmosphere.

Wind speed can be measured by using an **Anemometer**, and let the Height of Anemometer is z_0 .

By measuring the wind speed, (u_0) at anemometer height z_0 , the wind speed (u) can be calculated at any other height (z) by using the following formula.

$$u = u_0 \left[\frac{z}{z_0} \right]^k$$

where,

z_0 – Anemometer Height

z – Height, where the wind speed is to be measured

- u_0 - Wind Speed at z_0
 K - Wind Speed Constant
 = $\frac{1}{9}$ for larger lapse rates
 = $\frac{1}{3}$ for marked inversions
 = Normally taken as $\left(\frac{1}{7}\right)$

II. Atmospheric Stability and Inversions

Atmospheric stability is defined as the measure of atmospheric tendency to encourage or discourage the vertical motion and the vertical motion is directly related to the different types of weather conditions and its severity.

The degree of atmospheric stability is determined by the temperature difference between the air parcel and the air surrounding in it.

For every 1000ft increase in altitude, the temperature decreases by about 3.5° F (about 6.4° C/km). The rate at which the atmospheric temperature decreases with increase in altitude is called **Lapse Rate**.

When the **Reverse (or Negative) lapse rate** occurs, a dense-cold stratum of air at ground level gets covered by lighter-warm air at higher levels. This concept is called **inversions**.

During inversion, vertical air movement is stopped and pollution will be concentrated below the inversion layer (dense-cold air and ground level). Due to this temperature inversion, the atmosphere is stable, and every little mixing of air with air pollutants takes place. This is called **atmospheric stability** and at this condition, pollutants in the air do not dilute.

Occurring of inversions is very common in winter and autumn (the season before winter and after summer) seasons. At the time of inversions, visibility is highly reduced and pollutants are at maximum.

Types of Inversions

(i) Radiation Inversions

Inversions occur at night, when the earth loses heat by radiation and cools the air, in contact with it is called **Radiation inversions**.

In radiation inversions, the cool air stratum is covered by lighter-warm air and the vertical air movement is stopped, until the sun warms the lower air, in the next morning.

Radiation inversion is very common in winter than summer, (due to the reduced daytimes). Due to the restriction of horizontal air movement by surrounding high ground, radiation inversions may occur frequently in Valley areas.

(ii) Subsidence Inversion

Inversion occurring at moderate altitudes and often remains for several days, caused by sinking or subsiding of

air anti-cyclones. The air circulating around the area descends slowly at the rate of about 1000 m per day.

Anti-Cyclones are high pressure areas surrounded by low pressure areas.

III. Mixing Height

Mixing height is defined as the 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 other three factors.

- (a) Wind direction
- (b) Wind speed
- (c) Wind turbulence

IV. Precipitation and Rainfall

Rainfall or Precipitation is the secondary meteorological factors that exert a two-fold cleansing action on the pollutants, discharged into the atmosphere. Rainfall accelerates the deposition of particulate matter on the ground and hence, its concentration of gaseous pollutants which are soluble in water. Rainfall can be estimated by using various rain gauges.

V. Humidity

The moisture content of the atmosphere influences the corrosive action of air pollutants and represents the potentiality for fog formation.

Humidity is the quantity representing the amount of water vapour in the atmosphere.

VI. Radiation (Solar Radiation)

Solar radiation induces the chemical reactions between the atmospheric air components and pollutants in the air and the reaction rate depends on the location.

The application of all the above 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 its regular operation.

Also, these meteorological factors are used in the layout of zones for industrial use, in identifying causal factors in existing pollution problems and in establishing air quality criteria.

Solar radiation is the main heat source and it is absorbed at the ground level and hence, the temperature.

2.2. LAPSE RATE

The temperature of the ambient air (Surrounding air) decreases with increase in the altitude (height). The rate at which, the temperature changes with increasing height of the atmosphere is called **Temperature Lapse Rate**.

The lapse rate changes with respect to time and place. Even at the same place, the rate changes with time. However, the lapse rate can be determined by raising a balloon (attached with a thermometer), by the digital self-recording

mechanism and it is called Prevailing or Ambient or Environmental Lapse Rate (ELR)

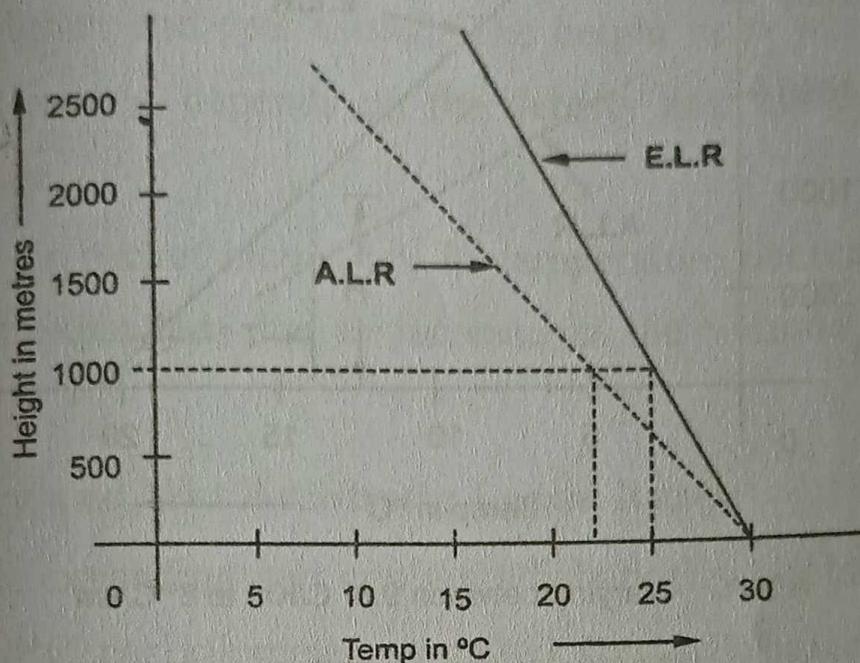


Fig. 2.1. (a) Sub Adiabatic Lapse Rate

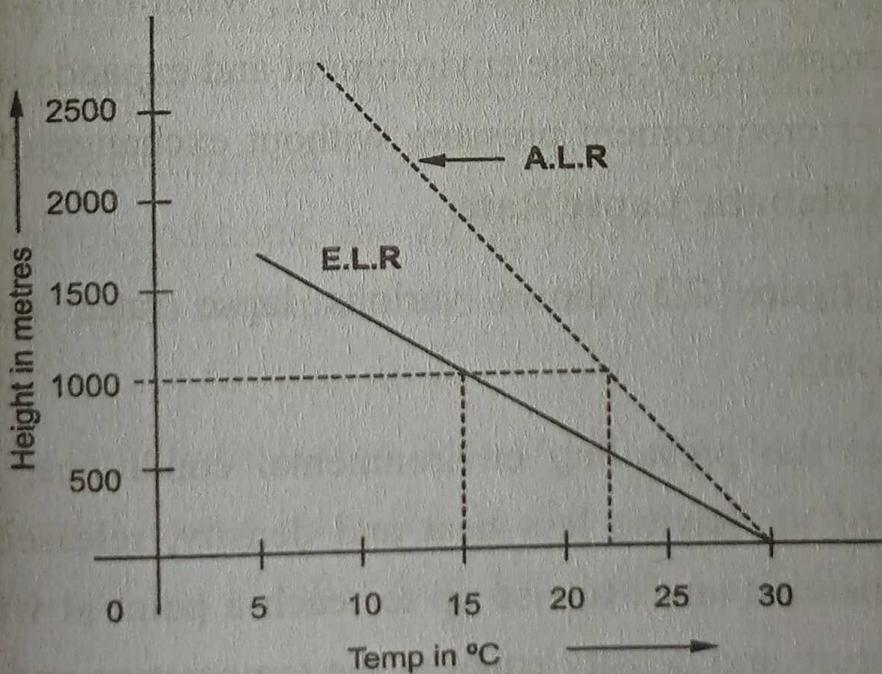
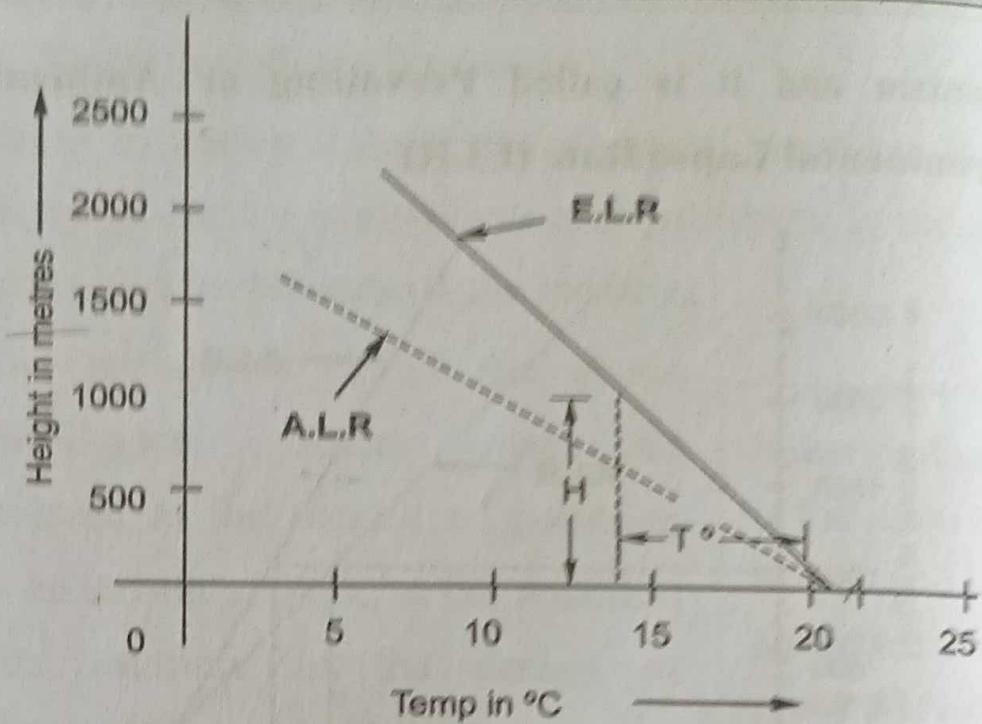


Fig. 2.2. (b) Super Adiabatic Lapse Rate



A.L.R - Varying between 9.8° C/Km to 6° C/km

$\frac{T}{H}$ - Varying between 9.8° C/Km to 6° C/km

Fig. 2.3. (c) Environmental Lapse Rate

The lapse rate of a parcel of dry air, when it lifts upwards in a hydrostatically-stable environment and expands slowly to the lower environment pressure without exchange of heat is called **Adiabatic Lapse Rate**.

The figure 2.3 shows various lapse rates and their relationship.

Under the prevailing environmental conditions, when a pocket of air having less heat and density, released to the atmosphere, it tends to rise up to reach a point at which the temperature and density equal to the temperature and density of the surrounding air.

When a pocket of heated air is released from an automobile or a stack to the environment, it rises up, expands, becomes lighter and gets cooled. The height upto which the air packet moves, depends on the density and temperature decrease rate.

As the air packet moves up, its temperature decreases as its heat is expanded, due to increase in the volume of air pocket.

2.2.1. Dry and Wet Adiabatic Lapse Rate

Dry air, expanding and cooling adiabatically cools at the rate of 9.8°C per kilometer, is called **Dry-adiabatic lapse rate**. In wet air, the expanding and cooling is calculated to be 6°C per kilometer and, is called **Wet-adiabatic lapse rate**.

When the Environmental Lapse Rate (ELR) is more than the adiabatic lapse rate it is called **Super-adiabatic lapse rate**, and the environment is an unstable, *i.e.*, at an unstable environmental conditions, the rising parcel of hotter-lighter air will continue to rise up and the downing cooler-denser air parcel will continue to come down.

When the **Adiabatic Lapse Rate** (ALR) is greater than the **Environmental Lapse Rate** (ELR), the environment is said to be **stable**, and this is called **Sub-Adiabatic Lapse Rate**.

When the ALR is equal to the ELR, the environment is a neutral one and this is called **Neutral Adiabatic Lapse Rate**.

When the temperature of the environment increases with altitude, then the lapse rate becomes inverted and this is called **negative lapse rate**.

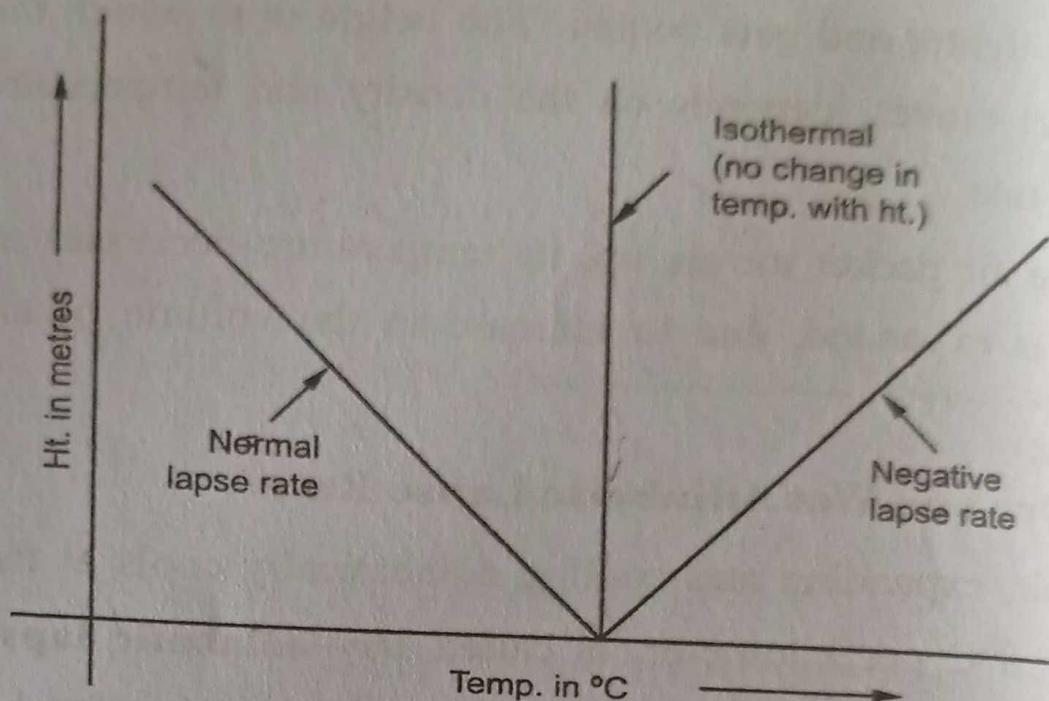


Fig. 2.4. Negative Lapse Rate

Negative lapse rate occurs under conditions generally called **inversion**. Temperature inversions represent a highly stable environment.

2.3. PLUME AND PLUME RISE

Plume is defined as the path and its extension in the atmosphere of the emitted gas from a source. The source is generally referred as **stack**. In general, plume is an air column, in which one air is moving through another.

Plume Rise is defined as the distance of the hot plume from the stack into the atmosphere, due to the buoyancy and momentum.

In air pollution, the diffusion of air pollutants into the environment is depending on the **environmental lapse rate** and **adiabatic lapse rate**.

The factors influencing the plume behaviour are as follows.

1. Stack Height
2. Diurnal Variation (in the atmosphere stability)
3. Seasonal Variation (long-term variation)

Stack Height

Emissions from the tall stacks, are generally allowed to mix with the atmospheric air (at higher levels) in order to increase the rate of dilution.

Ground Level concentration of the emission highly depends on the,

1. Height of the Stack
2. Height of the plume rise above stack.

The actual stack height (H) is easy to determine while effective stack height (H_e) is quite difficult to estimate with high degree of accuracy. The increased stack height is considered to diffuse the pollutants better.

Immediately above the stack, the rise of pollutant is proportional to the emission velocity of gases and to the temperature differences between the gases and the surrounding atmosphere.

For a given stack height, the concentration at ground level decreases with increase in wind velocity. However, there is a critical velocity, when the ground concentration attains its maximum value.

Maximum Concentration (C_m) of pollutants on ground level is given as,

$$C_m = \frac{M \cdot K}{H^2} \sqrt[3]{\frac{1}{V \cdot A_T}}$$

Where,

H – Height of the stack (in m)

K – Constant

M – Mass of the pollutant gases discharged per unit time

V – Volume of the pollutant gases discharged per unit time

A_T – Difference in temperature of stack gases and surrounding air

The constant value K depends on the following.

- (a) Horizontal and vertical mixing of pollutants in the air
- (b) Settling velocity of polluting substances
- (c) Discharge characteristics of the gases from stack.

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

The empirical formula for the stack height emitting maximum concentration of pollutants emission, developed by USSR, is given as,

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

Where,

A – Coefficient

- depends upon atmospheric condition
- 200 for Indian conditions

F – Coefficient

- depends upon dust precipitation efficiency
- varies from 0.8 to 0.95

M – Coefficient

- depends upon velocity of flue gases

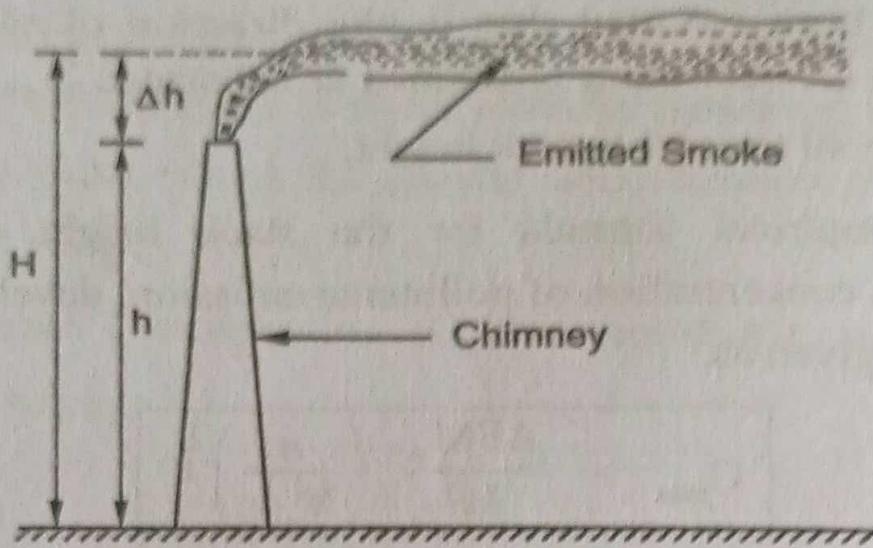
H – Height of stack or chimney (in m)

n – Number of emitting sources

V – Volume of gases leaving the chimney
in m^3/s .

t – Temperature difference between gases and
temperature at the top of the stack

M – Quantity of flue gases in g/s



$$H = h + \Delta h$$

where,

h - actual height of stack in m

Δh - Plume height in m

Fig. 2.5. Effective Stack Height

The value 'H', used in the above equation is the effective height of the Stack (or Chimney) and the actual height of the Stack is not to be used. This effective height consists of actual height (h) with the height to which the plume rises above the Stack before levelling out.

$$H = h + \Delta h$$

Holland's equation is also used to calculate the plume height (Δh)

$$\Delta h = \frac{V_s \cdot D}{u} \left[1.5 + 2.68 \times 10^{-3} PD \left(\frac{T_s - T_a}{T_s} \right) \right]$$

Where,

Δh - Rise of the plume above the stack (in m)

V_s - Stack gas velocity (m/sec)

D - Inside exit dia of the stack (in m)

u - Wind speed (in m/sec)

P - Atmospheric pressure (in millibars)

T_s - Stack gas temperature, (in °K)

T_a - Air temperature, (in °K)

2.3.1. Design of Stack Height

The following two formulae are given by the **Central Board for Prevention and Control of Air Pollution** based on various assumptions, are used to calculate the minimum height of the chimney for Indian Conditions.

$$(1) \quad h = 74 (Q_p)^{0.27}$$

where,

h - Chimney height

Q_p - PM emissions in tonnes/hour

$$(2) \quad h = 14 (Q_s)^{0.27}$$

where,

h - Chimney height

Q_s - SO_2 emission in kg/hour

The maximum of two heights calculated by the above equations should be considered for design.

From the above two equations, heights are subjected to the following minimum values.

1. Chimneys adopted for industries in general – 30 m
2. For Thermal power plants – 220 to 275 m

2.3.2. Objectives of Study of Plume Behaviours

Plume behaviour observations are used,

1. To determine the locations of air sampling
2. To identify the invisible pollutants
3. To change the plume pattern according with the seasonal variations

2.3.3. Types of Plume (Plume Pattern)

Various types of plume behaviour are described below.

1. Looping Plume
2. Neutral Plume
3. Coning Plume
4. Fanning Plume
5. Lofting Plume
6. Fumigating Plume
7. Trapping Plume

1. Looping Plume

Looping plume is defined as, the behaviour of plume which has wavy character and it occurs at a highly unstable atmosphere, due to the rapid mixing.

2. Neutral Plume

Neutral Plume is the upward vertical rise of the plume from the stack, which occurs, when the environmental lapse rate is approximately equal to the adiabatic lapse rate. The

upward movement of plume will continue, till the plume density equals the air density.

3. Coning Plume

Coning Plume is the plume behaviour in the shape of the cone above the plume line, which occurs at a slight stable environment. When the wind velocity is more than 32 km/h, coning plume occurs in a near neutral atmospheric (adiabatic condition). In this, the plume reaches the ground at greater distances than the looping plume.

4. Fanning Plume

Fanning plume is the horizontal plume pattern for a long-distance, occurs when there will not be a vertical mixing. Fanning plume occurs, under extreme inversion conditions due to the negative environmental lapse rate from the ground to certain heights.

It may extend even above the top of the stack, the emission will spread only in the horizontal direction, due to the high atmospheric stability.

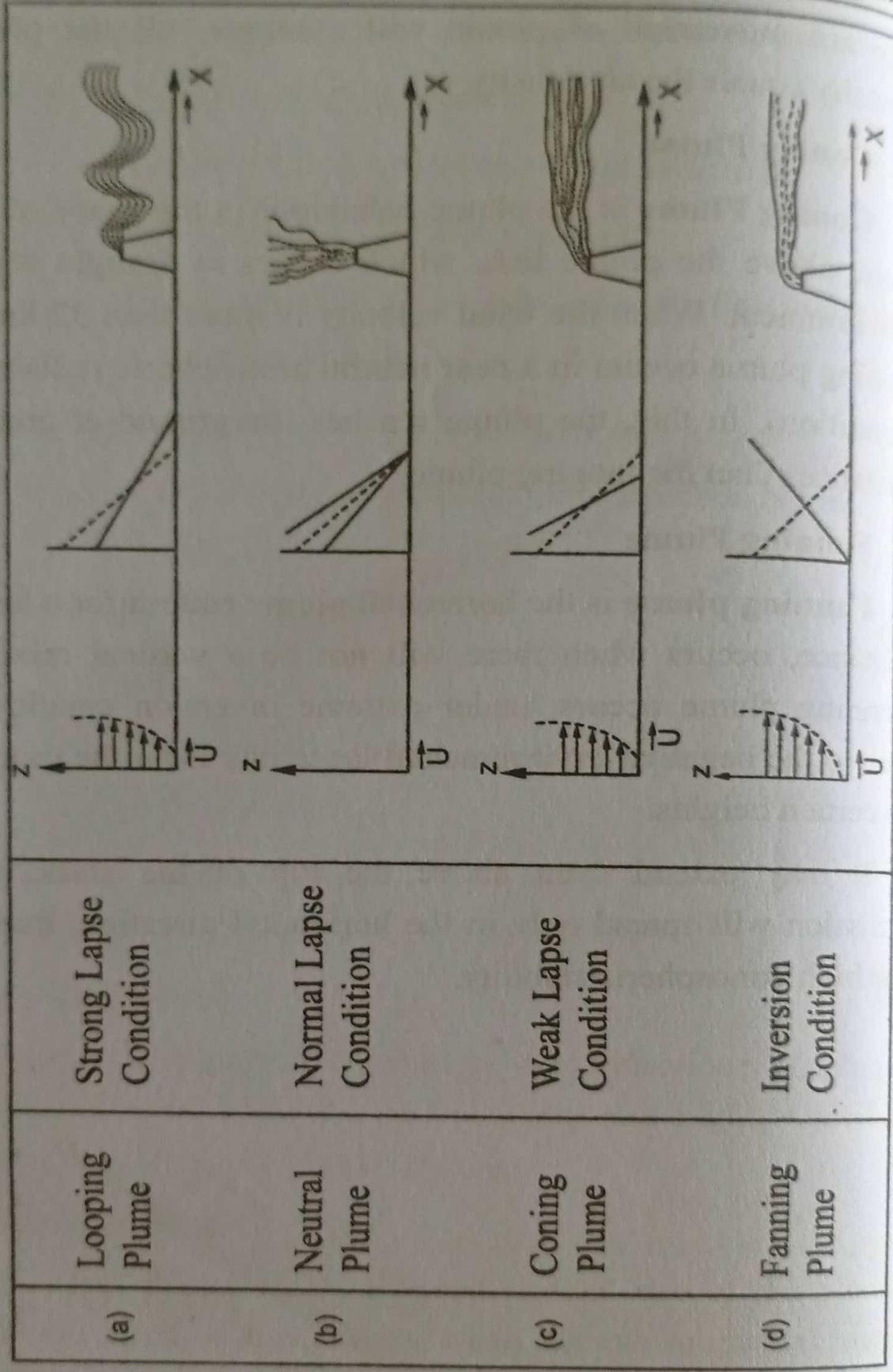


Fig. 2.6. Various Plume Behaviours

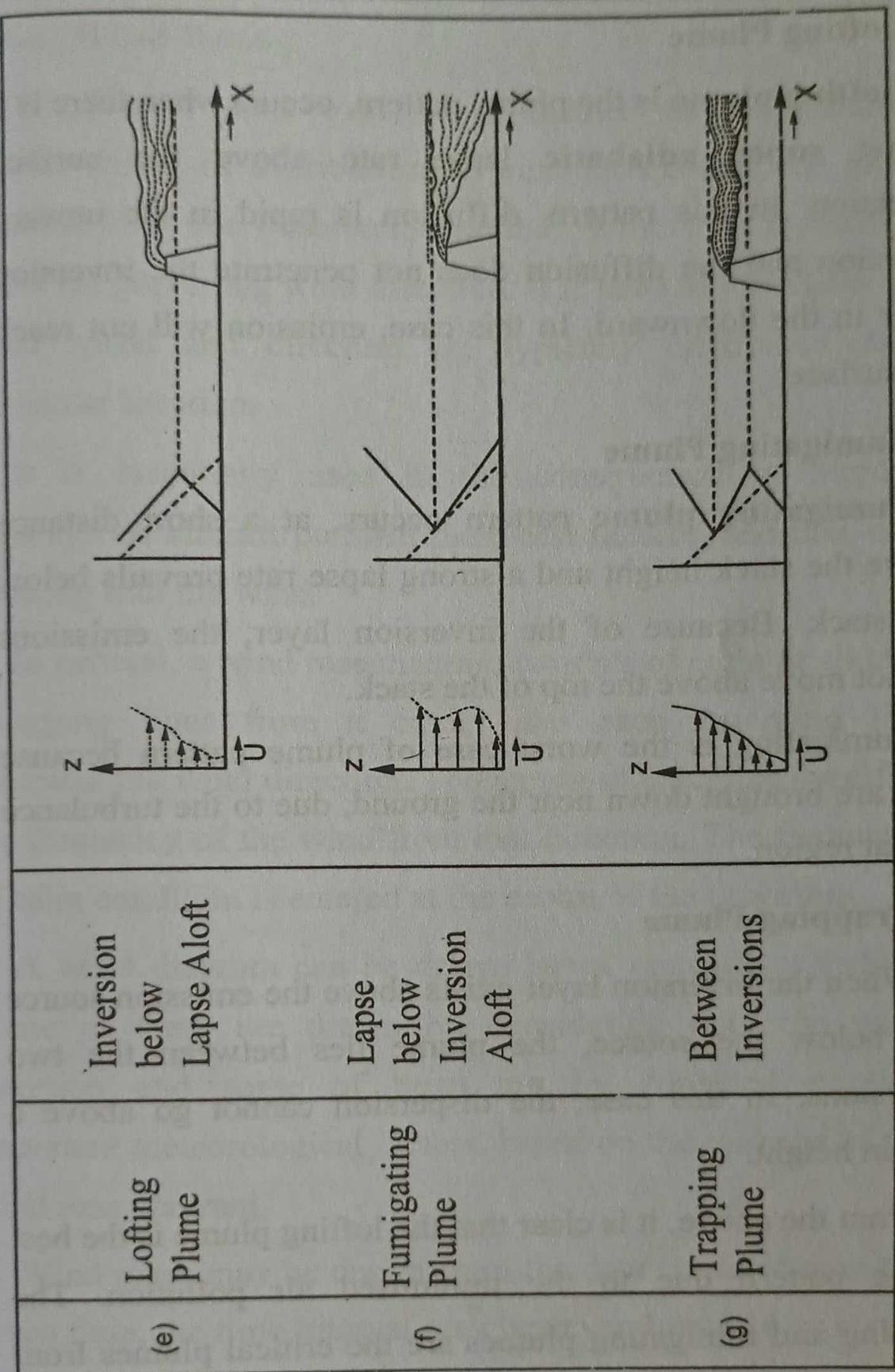


Fig. 2.7. Various Plume Behaviours

5. Lofting Plume

Lofting plume is the plume pattern, occurs when there is a strong super adiabatic lapse rate above the surface inversion. In this pattern, diffusion is rapid in the upward direction and the diffusion does not penetrate the inversion layer in the downward. In this case, emission will not reach the surface.

6. Fumigating Plume

Fumigating plume pattern occurs, at a short distance above the stack height and a strong lapse rate prevails below the stack. Because of the inversion layer, the emissions cannot move above the top of the stack.

Fumigating is the worst case of plume pattern because they are brought down near the ground, due to the turbulence in that region.

7. Trapping Plume

When the inversion layer exists above the emission source and below the source, the plume lies between the two inversions. In this case, the dispersion cannot go above a certain height.

From the above, it is clear that the lofting plume is the best plume pattern due to the minimised air pollution. The trapping and fumigating plumes are the critical plumes from the point of ground level pollutant concentrations.

2.3.4. Wind Rose

Wind rose at a location is defined as the pictorial representation of distribution of wind direction at the given location over the observation period. Wind rose is used to show the prevailing wind direction. It is used to view how the wind speed and direction are typically distributed at a particular location.

It is essentially used in the construction of airport-runways, as aircraft perform their best landing and take-offs pointing into the wind.

In general, a wind rose diagram consists of eight or sixteen emerging lines from a circle, and each emerging line indicates the wind direction. The length of each line specifies the frequency of the wind from that direction. The frequency of calm condition is entered at the centre of the diagram.

A wind diagram can be drawn based on various factors. Some of them are drawn by considering only the wind direction and some of them are by considering other important meteorological factors, based on the purpose of the wind rose diagram.

Wind roses may be drawn from the data obtained over the given time, the time interval may be several months or a year or a season. In wind roses, the meteorological factors are to

be converted into wind direction that refers to the direction from which the wind is blowing.

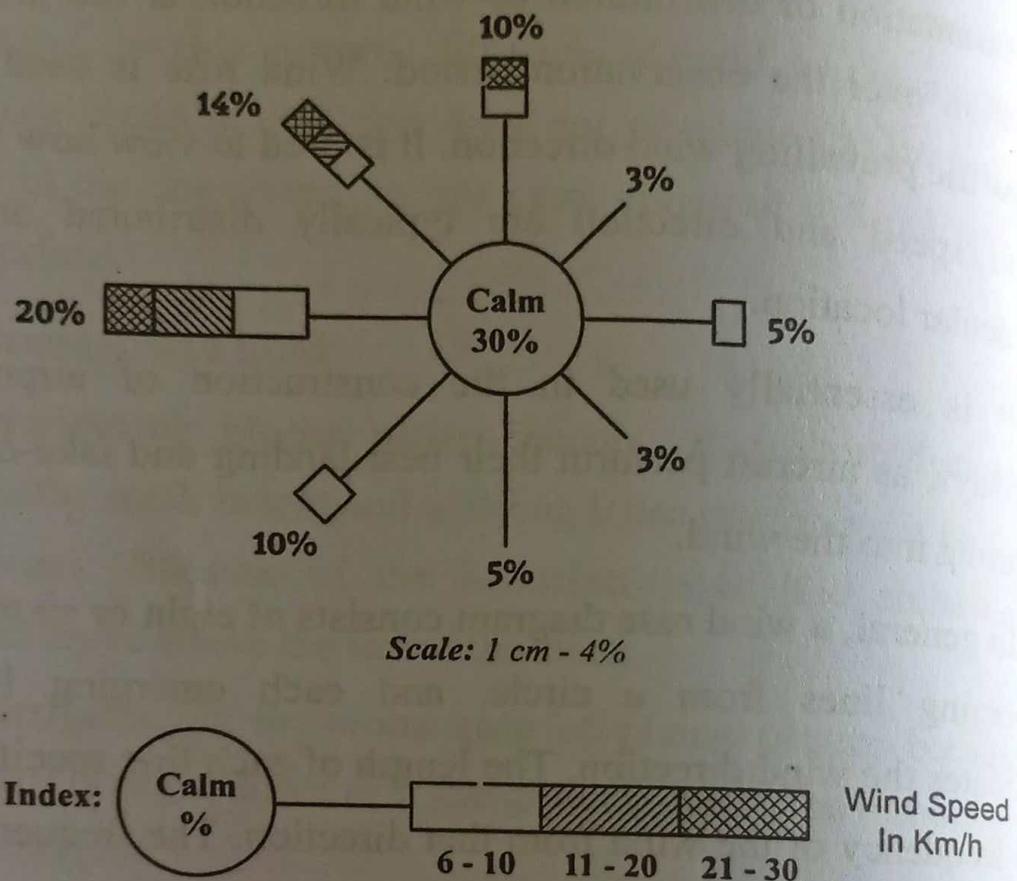


Fig. 2.8. Wind Rose Diagram

The frequency of winds blowing from the north is indicated by a line or bar extending to the north on the wind rose diagram.

Wind rose diagram is prepared using an appropriate scale to indicate the percentage frequencies of wind direction and appropriate index shades, lines etc., to represent various wind speeds.

Wind speed of less than 1 km/h is mentioned as calm in the wind rose diagram. Following are the special types of wind roses.

1. Precipitation wind rose
2. Smoke wind rose
3. SO₂ wind rose
4. HC wind rose

2.3.5. Pollution Roses

Pollution Roses are defined as the wind rose diagram and in which, various parameters of precipitation, smoke, sulphur-di-oxide, hydro carbons etc. are attached with the wind direction, instead of wind speed.

2.3.6. Types of Wind rose

1. Type I wind Rose (showing direction and duration of wind)
2. Type II Wind Rose (showing direction, duration and intensity of wind)

2.3.7. Plume Rise and Dispersion Theories

The dilution of atmospheric wastes from elevated stacks is considered to occur in two stages,

1. Plume rise and
2. 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 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.

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 involve,

1. Plume temperature
2. Rate of emission.
3. Stack parameters
 - (a) Height and diameter
 - (b) Meteorological factors (wind speed, direction etc.)
 - (c) The atmospheric stability
 - (d) The parameters representing the topography of the region.

The above parameters have been employed successfully in many stack design and pollution control problems.

I. Wind Tunnel Method

Wind Tunnel Technique is another method used to estimate the effectiveness of the diffusion of the atmospheric waste. In this method, a model of the stack and the adjoining area of interest are constructed in a wind tunnel, and the diffusion experiment conducted on the stack jets in that tunnel, satisfying the usual geometric and dynamic scaling parameters.

The formulas which are available and used to estimate or predicting the pollutants are generally obtained from uniform topographic and meteorological conditions. These problems can be eliminated by the **Wind Tunnel Method**. This method functions, based on the method of similitude between the actual flow condition and corresponding model in the wind tunnel.

In this case, a strong wind when turbulent mixing keeps the lapse rate in almost adiabatic condition and it may not be difficult to obtain the usual geometric and dynamic similitude. But the simulation of scales and intensities of turbulence, and the variation of **mean wind velocity** with height, is extremely difficult.

Turbulence is defined as the gas (or a fluid) flow, differentiated by its properties, changes with respect to time, which is formed due to the rapid variation of pressure, velocity etc.

Conventional tunnels fail in correct prediction when the atmospheric lapse rate controls the plume behaviour, as the temperature within the model is essentially isothermal. Many works are in progress to develop suitable simulation methods, which shows that the **Wind Tunnel Method** is the suitable method for solving the atmospheric diffusion problem.

II. Effect of Dilution

Before entering into the detailed description of plume rise and dispersion equations, it is important to consider the process of dilution of the atmospheric wastes from the high level stack effluents, and also the principle meteorological factors influencing potential air pollution.

The temperature of the atmosphere decreases with increase in height and the temperature gradient is closely interlinked with the stability for air masses and in the study of pollution in atmosphere, the temperature gradient (lapse rate) is of special significance. The temperature lapse rate γ is defined by,

$$\gamma = -\frac{dT}{dZ}$$

Where,

T – Temperature

Z – Vertical distance

The negative sign indicates drop in temperature and often this sign is neglected.

The atmosphere may be considered to be adiabatic, except near the surface where air exchanges heat. For the adiabatic arrangement, the lapse rate γ_d , = 1°C per 100 metres of height.

These conditions correspond to the neutral equilibrium in which a quantity of air can be displaced without showing any tendency to return to its original height or to move further away from it. The value of $0 < \gamma < \gamma_d$ refers to a **stable** condition. By a **stable** arrangement, a quantity of air when displaced from one height to another is forced back to its original position. When the displaced air tends to move farther away from its original position, the condition is known as **unstable**, i.e., $\gamma > \gamma_d$.

The lapse rate can be negative so that the temperature increases with height and this condition is exceedingly stable and the meteorologists call such a distribution an **inversion**, i.e., $\gamma_d < 0$.

Humidity has an influence on the distribution of temperature in the atmospheric air which is in general mixed with water vapour. If the water is in a gaseous state in air, its presence in small quantities makes little difference in the behaviour of the air mass as regards its stability. If, on the other hand, water vapour condenses, it affects the behaviour of the air since there is a great amount of heat release due to condensation.

The lapse rate, which may vary widely even in normal day conditions, plays an important role in the case of dilution of stack effluents in the atmosphere. The negative lapse rate or temperature inversion (the inversion layer may begin at ground level and extend up to a few hundred metres) may occur on clear nights with light winds when the air next to the surface is cooled by the cold ground surface. A low-level inversion always acts as a barrier to vertical dilution of the pollutants even in an unstable surface layer and thus leads to an increase in the intensity of air pollution near the ground.

Gustiness of wind plays an important role in the dilution of atmospheric wastes. **Gusts** are the manifestation of atmospheric turbulence and a quantitative measure of gustiness gives the magnitude of turbulence. In other words, gustiness, g' , is the measure of the fluctuation of the mean velocity of a turbulent wind in a particular direction.

If \bar{u} is the mean wind velocity in the x -direction, and v' is the component fluctuation of the mean wind in y -direction, then, the gustiness in the y -direction, g'_y , is given by,

$$g'_y = \frac{1}{\bar{u}} \sqrt{(v')^3}$$

Another important factor, wind-speed profile in the vertical plane, is a good measure of the degree of turbulence and atmospheric stability. In an unstable atmosphere, the variation in wind-speed profile with height is much less than under stable condition. If \bar{u}_1 is the mean wind at a particular

elevation z_1 , and \bar{u} can be the mean wind at any elevation z , \bar{u} can be expressed as follows as given by Sutton:

$$\bar{u} = \bar{u}_1 \left[\frac{z}{z_1} \right]^{n/(2-n)}$$

Where, n is the turbulence parameter, $0 < n < 1$.

The approximate value of n for a large lapse rate is 0.20 and for marked inversion is 0.50. Other meteorological factors which affect the turbulence or mixing of pollutants are humidity, vertical gradient in humidity, etc.

It is apparent that the form of stack emissions depends on the wind profile, turbulence of the wind, temperature distribution, etc.

III. Plume Rise and its Estimation

Plume rise is defined as the rising of the emissions (or plume) to a certain distance into the atmosphere due to the velocity and temperature.

The level of pollution at a location highly depends on the height of the stack. The '**effective height**' of a stack is the sum of total height of the stack and the rise of the plume beyond the stack exit. The plume rise depends on many factors as follows.

1. Exit velocity
2. Wind speed
3. Diameter of the stack

4. Temperature of the plume

5. Lapse rate, etc.

The plume rise can be calculated by using number of formulas and one of the formula is given below.

$$\Delta h = K \cdot \frac{Q_\alpha}{\bar{u}_\beta}$$

Where,

α , β and K – Constants

T_m – Mean Temperature during measurements

In **Canadian Combustion Research Laboratory**, the values of α , β and K are estimated as $\frac{1}{4}$, 1, 66.4 respectively.

Q is expressed in K cal/sec and \bar{u} is in terms of m/sec, where K is the function of height of the source emission.

In another method, the plume rise can be computed by the theory of buoyancy and momentum.

$$\Delta h = \Delta h_{\text{buoyancy}} + \Delta h_{\text{momentum}}$$

Moses and Carson introduced the following formula for plume rise height.

$$\Delta h = C_1 \frac{V_s \cdot d}{\bar{u}} + C_2 \frac{Q(h^{\frac{1}{2}})}{\bar{u}}$$

Where,

Δh – Plume rise in m

V_s – Stack exit velocity (m/sec)

\bar{u} - Wind Speed (m/sec)

d - Stack diameter (in m)

Q_h - Heat emission rate (K° cal/sec)

C_1, C_2 - Plume rise regression co-efficients

- depends on the atmospheric stability

In the above formula, the first term evaluates the vertical momentum of the gases leaving the stack. The second term evaluates the buoyancy force of the plume, which is a function of heat content of the plume. Hence, the magnitude of the plume rise is inversely proportional to the wind speed, directly proportional to the sum of mass ejection rate, and square root of heat content of the gases.

The BIS has suggested that the following **Brigg's formula**, be used to compute plume rise for practical use.

- (a) For hot effluents with heat release of the order of 10^6 cal/sec or more.

$$\Delta h = 0.84 (12.4 + 0.09 h) \frac{Q_h^{1/4}}{\bar{u}}$$

Where,

Q_h - Heat release in calories per second

h - Height of the stack in meters

\bar{u} - wind speed (in m/sec)

- ii). For low heat releases and which can be mounted as momentum sources above.

$$\Delta h = \frac{3 W_o D}{\bar{u}}$$

Where,

W_o – Efflux velocity of the same units as \bar{u}

D – Stack exit diameter

It may be noted that, even though the available plume rise formulae, predicts well in a particular place for some particular conditions, nothing can be completely accepted due to the empirical behaviour. The lack of a complete theory concerning the rise of plumes in the atmosphere is probably a barrier to the environmentalists in the prediction of downwind pollution levels.

2.4. METHODS OF MEASURING METEOROLOGICAL VARIABLES

The instrument which is used for meteorological factors should have higher degree of accuracy and sensitivity. Also, it should be simple and durable. The National Environmental Engineering Research Institute (NEERI) has developed some devices for measuring the meteorological factors. The devices are,

1. Wind Direction Recorder
2. Wind Speed Recorder
3. Temperature Measurement
4. Solar Radiation Measurement

2.4.1. Wind Direction Recorder

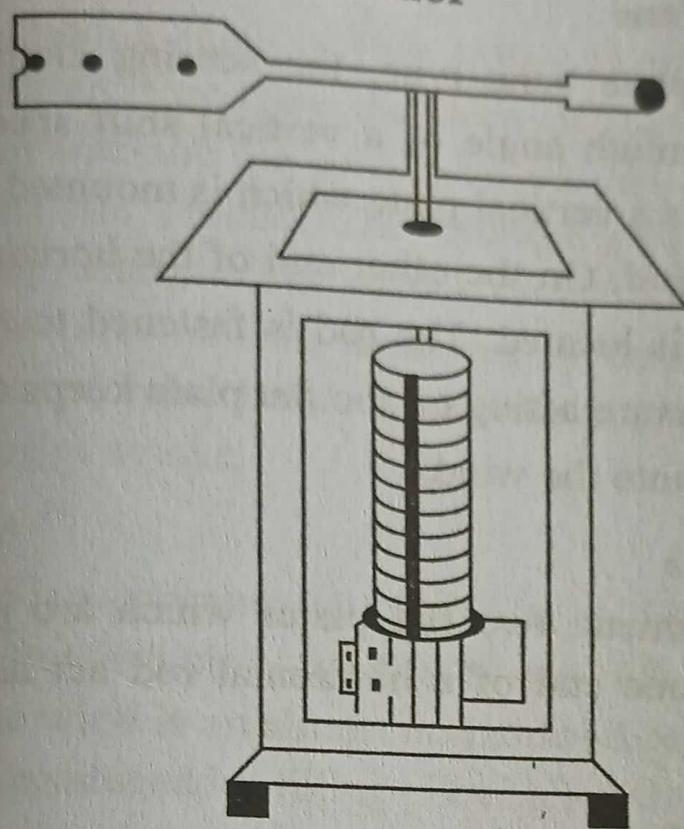


Fig. 2.9. Wind Direction Recorder

Wind direction recorder of the NEERI for measuring wind direction employs the conventional wind vane to sense the wind direction. It is automatic and operated mechanically without any power supply. The instrument continuously records the wind direction on a chart attached with the instrument.

I. 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

1. Flat Plate Vane

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

2. 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.

3. Aerofoil vane

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

4. Running average anemograph

It is always better to measure the average wind speed and direction, if possible. While averaging the wind direction, a problem occurs from the process of differentiating $0^\circ - 360^\circ$ as the wind direction fluctuates around north.

An anemograph which automatically produces the running averages of both wind speed and direction has been developed.

II. 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 methods are discussed, below.

(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 is 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 is 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.

2.4.2. Wind Speed Recorder

Anemometer is the instrument used for measuring wind speed. 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.

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, to the pen which makes a continuous rise and fall impression on chart paper. This rate of rise or fall is proportional to the wind speed.

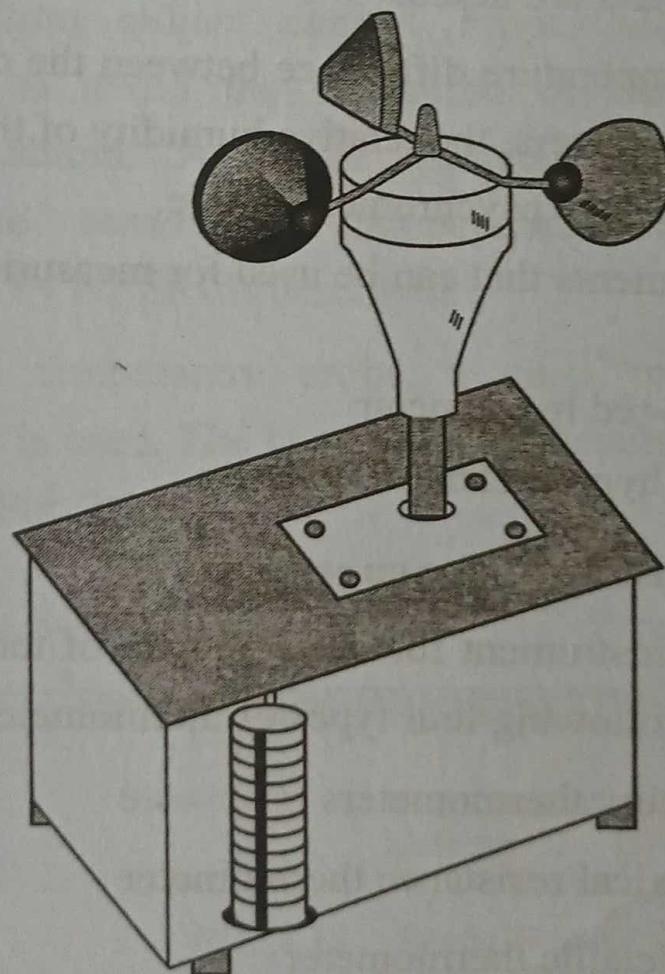


Fig. 2.10. Wind Speed Recorder

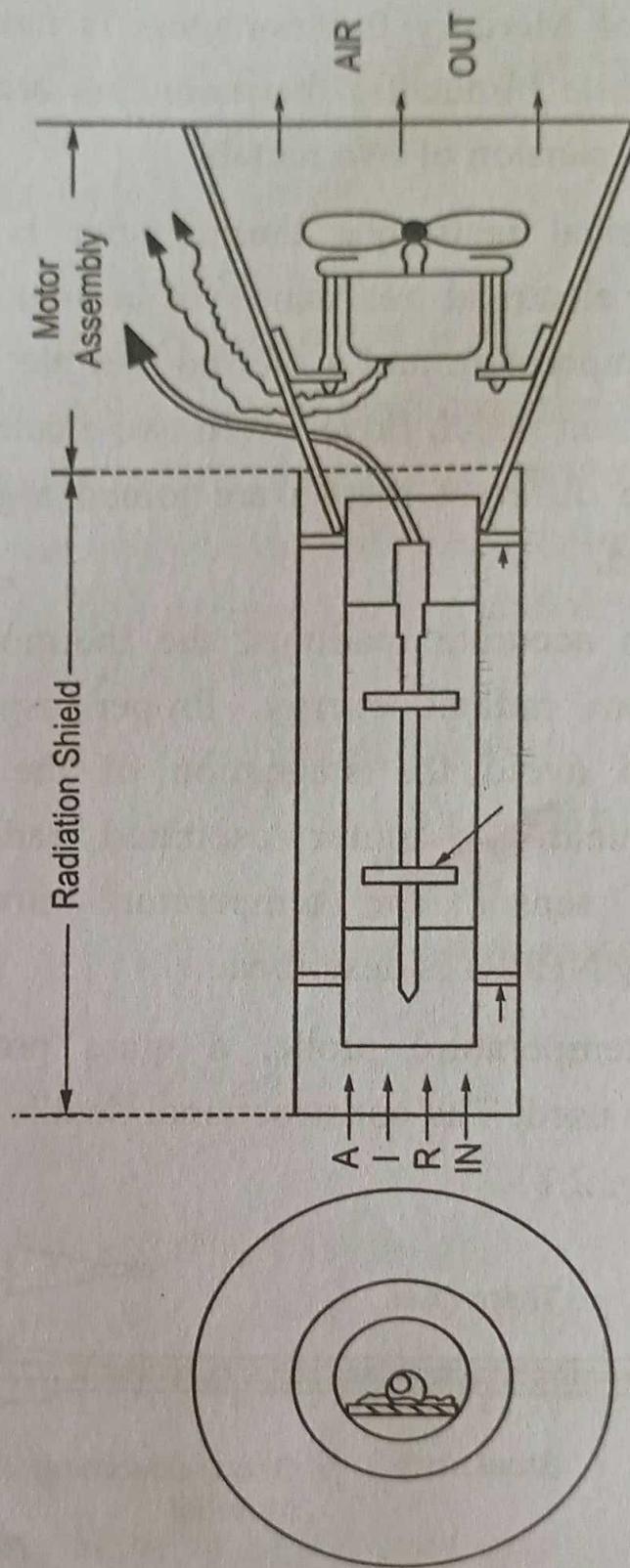


Fig. 2.12. Motor Aspirated Radiation Shielded Temperature Sensor

Two core shielded electrical contacts are taken from the thermistor leads. The thermistor is first wrapped in a shock absorbing material and is put into an exactly fitting stainless steel tube.

A thin walled conical shaped metallic tip is fixed at one end of the stainless steel tube. The thermistor is pushed until its sensitive point makes a positive thermal contact with the thin walled metallic tip. The open end of the stainless steel tube is closed with a PVC cap and the joint is made watertight with some adhesive.

Figure 2.12 gives the details of the radiation shield. It consists of two concentric PVC pipes A and B separated from each other by an air layer and supported at two positions by two polyvinyl chloride (PVC) rings R_1 , and R_2 . PVC is preferred as it is a good heat insulator and at the same time is also a light material with sufficient strength.

The temperature probe (TP) is positioned on the axis of the inner pipe with the help of a PVC sheet (S) and clamps C_1 and C_2 . The tip of the probe is kept 5-8 cm inside from the edges of the outer pipe and about 2.5 cm from the edges of the inner pipe.

The outer surface of the outer pipe and the ends of the inner and outer surfaces of both the pipes are covered with aluminium foil having good emissivity.

A fan assembly is fixed at the other end of the pipes. A small fan (F) driven by a motor (M) working on 9-12 volts (DC) and mounted in a funnel shaped support, aspirates the air over the probe.

2.4.5. Solar Radiation Measurement

Knowledge of sunlight intensity is important especially in places where photochemical smog formation takes place. Instruments used to measure the radiant energy from the sun are,

1. Pyrheliometer
2. Solarimeter
3. Chemical actinometer etc.

2.5. DISPERSION OF POLLUTANTS

When the air pocket, containing air pollutants, released to the atmosphere from a source, it gets dispersed into the atmosphere to various directions, depending upon the prevailing winds, temperature and pressure conditions in the environment. Under the normal environmental conditions, when a packet of air (which is hotter and lighter than the surrounding air) is released to the atmosphere, then it tends to rise up and reaches a level, at which its temperature and density becomes equal to the surrounding air.

2.5.1. Factors affecting dispersion of pollutants

Various factors affecting dispersion of pollutants in the atmosphere are,

- ◆ Source Characteristics
- ◆ Emission rate of pollutant

- ♣ Stack height
- ♣ Exit velocity of the gas
- ♣ Exit temperature of the gas
- ♣ Stack diameter
- ♣ Meteorological Conditions
- ♣ Wind velocity
- ♣ Wind direction
- ♣ Ambient temperature
- ♣ Atmospheric stability

2.5.2. Dispersion Equations

The dispersion of pollutants is due to the turbulent flow of the wind. It is depending on the atmospheric stability, gustiness etc. Generally dispersion is a three dimensional approach, and the solution for that approach is mathematically difficult. Hence three dimensional equations are required to get the solution. These equations (or models) estimate the concentration of pollutants in the plume at any distance x , y and z in the horizontal down-wind direction, cross-wind direction and vertical wind direction respectively.

The turbulent diffusion models for atmospheric pollutants are based on **Fick's law** of molecular diffusion. Assuming K_x , K_y and K_z are **Eddy-Diffusivity Co-efficients** in three directions and applying the continuity in the atmosphere, we get,

$$\frac{\partial C}{r t} = \begin{cases} \frac{\partial}{\partial x} \left[K_x \cdot \frac{\partial c}{\partial x} \right] + \frac{\partial}{\partial y} \left[K_y \cdot \frac{\partial c}{\partial y} \right] \\ + \frac{\partial}{\partial z} \left[K_z \cdot \frac{\partial c}{\partial z} \right] + Q_{x,y,z} \end{cases}$$

Where,

$Q_{x, y, z}$ - Source or Sink expressed in appropriate terms

In the above equation, the value K_x , K_y and K_z will vary with respect to location and time and hence, the equation will be comprehensive.

On the basis of the Fick's law, Gaussian developed a statistical equation called **Gaussian Dispersion Equation**, and is given as,

$$\left. \begin{array}{l} \text{Concentration} \\ \text{of pollution} \end{array} \right\} = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp \left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \begin{array}{l} \text{horizontal} \\ \left. \begin{array}{l} \exp \left[-\frac{1}{2} \left(\frac{z-H}{\sigma_z} \right)^2 \right] + \exp \left[-\frac{1}{2} \left(\frac{z+H}{\sigma_z} \right)^2 \right] \end{array} \right\} \end{array} \begin{array}{l} \text{vertical} \end{array}$$

Where, C - Concentration of Pollutant (in gm/m^3)

Q - Emission rate of the pollutant (gm/sec)

- Mean wind velocity (in m/sec)

x - Downwind horizontal distance (in km)

y - Crosswind distance (in m)

σ_y - Plume's Standard Deviation in cross-wind direction (in m)

σ_z - Plume's Standard Deviation in vertical direction (in m)

H - Effective stack Height

Table 2.1. Pasquill's Stability Categories

Surface Wind Speed (m/sec) at z = 10 m	Day			Night	
	Incoming Solar Radiation			Thin overcast or (4/8) Low cloud	< (3/8) cloud
	Strong	Moderate	Weak		
< 2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
4-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

The horizontal and the vertical dispersion coefficients in Gaussian plume calculations can be approximated as,

$$\sigma_y(x) = ax^{0.894} \text{ and } \sigma_z(x) = cx^d + f$$

Where,

x - Downwind distance, in kilometer (km)

a, c, d and f - Constants, given in the table below.

$\sigma_y = ax^b$ and b is always = 0.894

Table 2.2. Constants for calculating Dispersion Coefficients

Stability Category	a	x < 1 km			x > 1 km		
		c	d	f	c	d	f
A	213	440.8	1.941	9.277	459.7	2.094	-9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68.0	33.2	0.725	-1.7	44.5	0.516	-13.0
E	50.5	22.8	0.678	-1.3	55.4	0.305	-34.0
F	34.0	14.35	0.740	-0.35	62.6	0.180	-48.6

In the downwind horizontal direction along the centerline of the plume, (When concentration is required only along x - direction) then $y = 0$.

$$C_{x,0} = \frac{Q}{\pi u \sigma_z \cdot \sigma_y} \cdot e^{-\frac{1}{2} \left(\frac{H^2}{\sigma_z^2} \right)}$$

When the smokes are emitted at ground level, the effective stack height (H) is zero.

The maximum ground level concentration occurs, where $\sigma_z = 0.707 H$, provided $\left(\frac{\sigma_z}{\sigma_y}\right)$ is constant with downwind distance x .

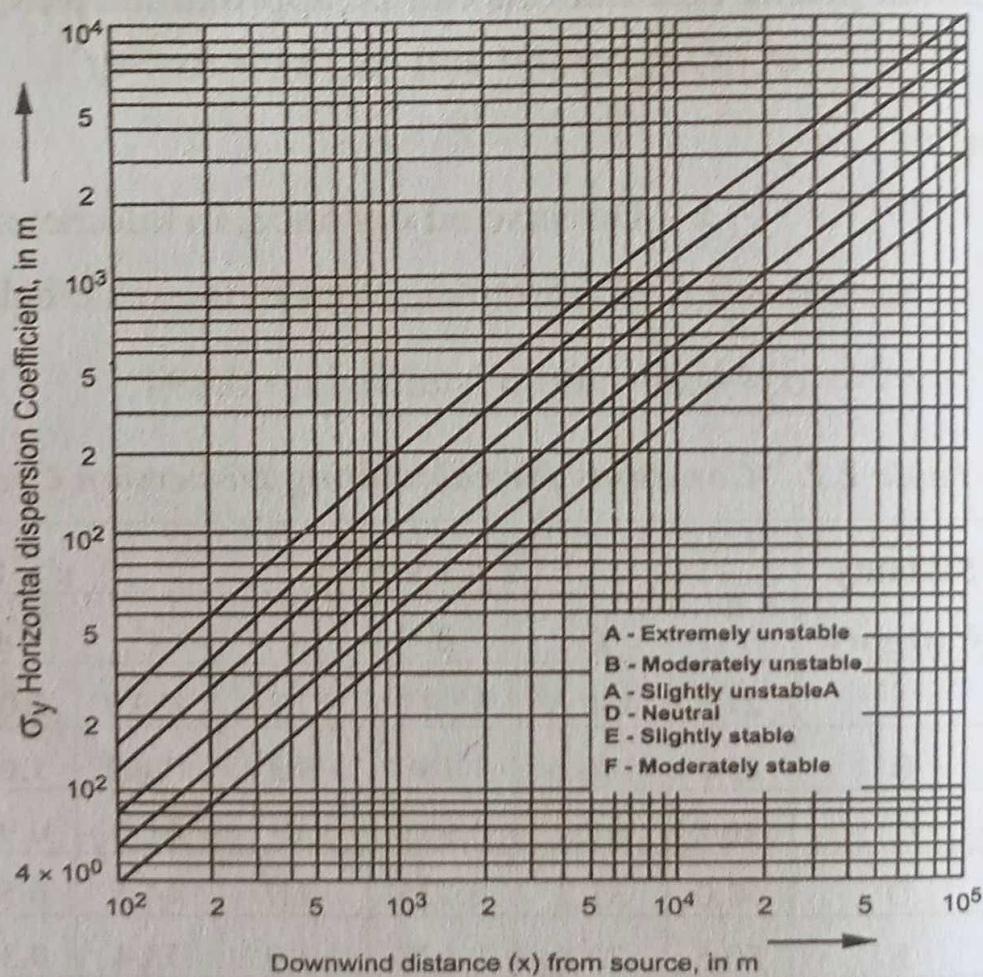


Fig. 2.13.

Numerical Values for Horizontal Diffusion (σ_y)

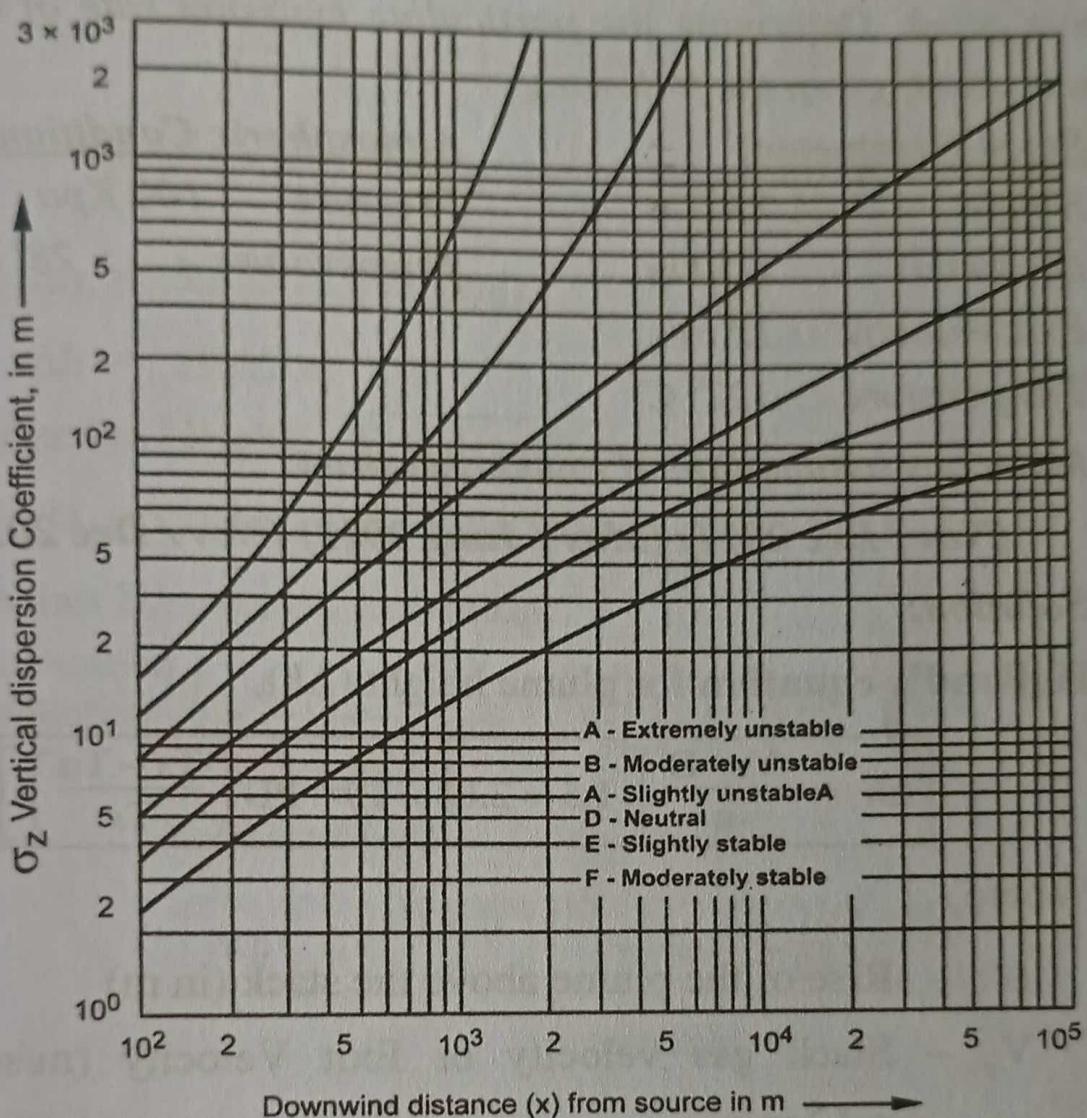


Fig. 2.14.

Numerical Values for Vertical Diffusion (σ_y)

Values of σ_x and σ_y are the function of downward distances (x) and atmospheric stability. Values of σ_y and σ_z for various values of x and different types of atmospheric stabilities are also given in figure 2.13 and 2.14.

Example 2.1 On a summer afternoon with a wind speed of 3.20 m/s the concentration of particulate matter was found to be 1520 $\mu\text{g}/\text{m}^3$ at a point 2 km down wind and 0.5

km perpendicular to the plume centerline from a coal fired power plant. Determine the particulate emission rate of the power plant, given the following:

Stack Parameters

Height : 75.0 m

Diameter : 1.50 m

Exit Velocity : 12 m/s

Temperature : 322° C

Atmospheric Condition

Pressure : 100 Kpa

Temperature : 28° C

Make any assumption, if found necessary.

(Nov / Dec 2011) (May / June 2012) (Nov / Dec 2012)

Solution:

Holland's equation for plume height (Δh),

$$\Delta h = \frac{V_s \cdot D}{u} \left[1.5 + 2.68 \times 10^{-3} PD \left(\frac{T_s - T_a}{T_s} \right) \right]$$

Where,

Δh – Rise of the plume above the stack (in m)

V_s – Stack gas velocity or Exit Velocity (m/sec)
= 12 m/s

D – Inside exit dia of the stack (in m) = 1.50 m

u – Wind speed (in m/sec) = 3.20 m /s

P – Atmospheric pressure (in millibars) = 100 Kpa
= 1000 millbars [1 kPa = 10 millibar]

T_s – Stack gas temperature, (in °K)
= 322° C = 322+273 = 595 °K

T_a – Air temperature, (in °K) = 28° C
= 28+273 = 301 °K

Substituting,

$$\Delta h = \frac{12 \times 1.5}{3.2} \left[1.5 + \left(2.68 \times 10^{-3} \times 1000 \times 1.5 \times \left[\frac{595 - 301}{595} \right] \right) \right]$$

$$\Delta h = 5.625 (1.5 + 1.986)$$

$$\Delta h = 19.61 \text{ m}$$

Effective Height, $H = h + \Delta h$

$$H = 75\text{m} + 19.6\text{m} = 94.691 \text{ m}$$

Gaussian Dispersion Equation

$$\left. \begin{array}{l} \text{Concentration} \\ \text{of pollution} \\ C \end{array} \right\} = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp \left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \quad \begin{array}{l} \text{centre line} \\ \text{horizontal} \end{array}$$

$$\left. \begin{array}{l} \left\{ \exp \left[-\frac{1}{2} \left(\frac{z-H}{\sigma_z} \right)^2 \right] + \exp \left[-\frac{1}{2} \left(\frac{z+H}{\sigma_z} \right)^2 \right] \right\} \\ \text{vertical} \end{array} \right.$$

Where,

C - Concentration of Pollutant (in gm/m^3)
 $= 1520 \mu\text{g/m}^3$

Q - Emission rate of the pollutant (gm/sec)

μ - Mean wind velocity (in m/sec) = 3.20 m/s

y - Crosswind distances (in m) = 500m

σ_y - Plume's Standard Deviation in cross-wind direction (in m)

σ_z - Plume's Standard Deviation in vertical direction
(in m)

H - Effective stack Height = 94.61 m

From the table 2.1, Pasquill's Stability Categories, For Wind speed, $u = 3.20$ m /s and Summer Afternoon (Strong-Incoming Solar Radiation), stability category (A-B) selected. Category, B is assumed for this calculation.

The value of σ_y and σ_z can be calculated as follows.

$$\sigma_y(x) = a x^{0.894} \text{ and}$$

$$\sigma_z(x) = c x^d + f$$

From table 2.2, for Stability Category B and $x = 2$ km ($x > 1$ km), the value of

$$a = 156, c = 108.2, d = 1.098 \text{ and } f = 2.0$$

Substituting,

$$\sigma_y = 156 (2.0)^{0.89}$$

$$= 289.898 \text{ or } 290 \text{ m}$$

$$\sigma_z = 108.2 (2.0)^{1.098} + 2.0$$

$$= 233.61 \text{ or } 234 \text{ m}$$

$$\left. \begin{array}{l} \text{Concentration} \\ \text{of pollution} \end{array} \right\} = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp \left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right]$$

centre line *horizontal*

$$\left\{ \exp \left[-\frac{1}{2} \left(\frac{z-H}{\sigma_z} \right)^2 \right] + \exp \left[-\frac{1}{2} \left(\frac{z+H}{\sigma_z} \right)^2 \right] \right\}$$

vertical

$$1520 = \frac{Q}{2\pi(290)(290)(3.2)} \left[e^{-\frac{(500)^2}{2(290)^2}} \right] \left\{ e^{-\frac{(-94.6)^2}{2(234)^2}} + e^{-\frac{(94.6)^2}{2(234)^2}} \right\}$$

$$1520 = \frac{Q}{1.36 \times 10^6} (0.26) (0.921 + 0.921)$$

$$Q = 4.965 \times 10^9 \mu\text{g/s}$$

$$Q = 4965 \text{ g/s}$$

2.6. DISPERSION MODELS

Dispersion models are mathematical simulation or approaches made to the dispersion of pollutants to study how air pollutants disperse in the ambient atmosphere. The dispersion models vary depending on the mathematical calculations used to develop the model.

The dispersion models vary depending on the mathematics used to develop the dispersion model.

The dispersion models require the following details.

a) Meteorological Factors

- Wind speed and direction,
- The amount of atmospheric turbulence
- Ambient air temperature
- The height to the bottom of any inversion aloft that may be present
- Cloud cover
- Solar radiation.

b) Sources of Emission

- The concentration or quantity of toxins in emission (or accidental release)
- Temperature of the material

c) Emissions Parameters

- Source location and height
- Type of Source (i.e., fire, pool or vent stack)
- Exit velocity
- Exit temperature and
- Mass Flow Rate or release rate.

d) Terrain elevations at the source location

- The receptor location (nearby homes, schools, businesses and hospitals)
- The location, height and width of any obstructions (such as buildings or other structures) in the path of the emitted gaseous plume, surface roughness.

2.6.1. Types of Air Pollution Dispersion Models

There are five types of air pollution dispersion models.

a) Box model

The box model is the simplest of the model types. It assumes the **air shed** (i.e., a given volume of atmospheric air in a geographical region) is in the shape of a box. It also assumes that the air pollutants inside the box are homogeneously distributed and uses that assumption to estimate the average pollutant concentrations anywhere within the air shed.

This model is very limited in its ability to accurately predict dispersion of air pollutants over an air shed because the assumption of homogeneous pollutant distribution is much too simple.

b) Gaussian model

The Gaussian model is the oldest and most commonly used model type. It assumes that the air pollutant dispersion has a Gaussian distribution, (meaning that the pollutant distribution has a normal probability distribution). Gaussian models are generally used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources. Gaussian models may also be used for predicting the dispersion of non-continuous air pollution plumes (called *puff models*). The primary algorithm used in Gaussian modeling is the **Generalized Dispersion Equation for a Continuous Point-Source Plume**

c) Lagrangian model

Lagrangian dispersion model mathematically follows pollution plume parcels (also called **particles**) as the parcels move in the atmosphere and they model the motion of the parcels as a random walk process. The Lagrangian model calculates the air pollution dispersion by computing the statistics of the trajectories of a large number of the pollution plume parcels. A Lagrangian model uses a moving frame of reference as the parcels move from their initial location. It is said that an observer of a Lagrangian model follows along with the plume.

d) Eulerian model

Eulerian dispersions model is similar to a Lagrangian model in that it also tracks the movement of a large number of pollution plume parcels as they move from their initial location. The most important difference between the two models is that the Eulerian model uses a fixed three-dimensional Cartesian grid as a frame of reference rather than a moving frame of reference. It is said that an observer of an Eulerian model watches the plume go by.

e) Dense Gas Model

Dense gas models are models that simulate the dispersion of dense gas pollution plumes (i.e., pollution plumes that are heavier than air). Based on the stability classification in the field of atmospheric diffusion, the three following well known models are used.

1. Pasquill Model
2. ASME (American Society of Mechanical Engineers) Model
3. McElroy Model

2.6.2. Applications of Dispersion Models

Following are the applications of dispersion models.

1. Air Quality Assessment
2. Estimation of downwind ambient concentration of air pollutants
3. Calculation of toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases.

4. Estimation of predict future concentrations under specific scenarios (i.e. changes in emission sources).

Example 2.2 Determine the effective height of a stack from the following data.

Wind Velocity, $u = 3 \text{ m/sec}$

Air temperature = 21°C

Physical Stack = $\begin{cases} 200 \text{ m with} \\ 0.98 \text{ m inside diameter} \end{cases}$

Atmospheric pressure = 1000 millibars

Stack gas velocity = 11.12 m/sec

Stack gas temperature = 160°C

☺Solution:

From the given data,

Wind Velocity, $u = 3 \text{ m/sec}$

Stack height, $h = 200 \text{ m}$

$D = 0.98 \text{ m}$

Atmospheric temperature = 21°C

$T_a = 21 + 273 = 294^\circ\text{K}$

Stack Gas Temperature, $T_s = 160^\circ\text{C}$

= $160 + 273 = 433^\circ\text{K}$

Atmospheric Pressure, $P = 1000 \text{ millibars}$

Stack gas velocity, $V_s = 11.12 \text{ m/sec}$

Rise of the plume above the Stack, Δh

$$= \frac{V_s \cdot D}{u} \left[1.5 + 2.68 \times 10^{-3} PD \left(\frac{T_s - T_a}{T_s} \right) \right]$$

$$\begin{aligned}
 &= \frac{11.12 \times 0.98}{3} \left[1.5 + 2.68 \times 10^{-3} \times 1000 \times 0.98 \right. \\
 &\quad \left. \times \left(\frac{433 - 294}{433} \right) \right] \\
 &= 3.633 [1.5 + 0.843]
 \end{aligned}$$

$$\Delta h = 8.513 \text{ m}$$

Effective Height of the Stack,

$$H = h + \Delta h$$

$$= 200 + 8.513$$

$$H = 208.513 \text{ m}$$

Example 2.3 An industry uses 3.6 ml of oil fuel per year. It has also been calculated that for every 1 ml of fuel oil burnt in the industry per year, the quantities of various pollutants, emitted are given below.

$$PM = 3 \text{ t/year}$$

$$SO_2 = 60 \text{ t/year}$$

$$NO_X = 8 \text{ t/year}$$

$$\text{Hydro Carbon HC} = 0.5 \text{ t/year}$$

$$\text{Carbon Monoxide CO} = 0.5 \text{ t/year}$$

Calculate the required height of Chimney for safe dispersion of the pollutants.

☺ **Solution:**

(i) By using the equation, $h = 74 (Q_p)^{0.27}$

Where,

$$Q_p = \begin{cases} \text{emissions of particulate matters in} \\ \text{tonners/hour} \end{cases}$$

$$= 3 \times 3.6 \text{ tonnes/year}$$

$$= 10.8 \text{ tonnes/year}$$

Assume the industry is working 20 hours in a day for 300 days in a year.

$$Q_p = \frac{10.8}{300 \times 20}$$

$$= 1.8 \times 10^{-3} \text{ tonnes/hour}$$

$$h = 74 (Q_p)^{0.27}$$

$$= 74 (1.8 \times 10^{-3})^{0.27}$$

$$= 13.43 \text{ m}$$

The height of 13.43 m chimney is required for the effective disposal of Particulate Matter.

(ii) By using equation $h = 14 (Q_s)^{\frac{1}{3}}$

Where,

$$Q_s = \text{SO}_2 \text{ in (kg/hour)}$$

$$\text{SO}_2 \text{ emissions} = 60 \text{ tonnes/year/ml of oil}$$

$$= \frac{60 \times 1000}{300 \times 20} \times 3.6$$

$$= 36 \text{ kg/hour}$$

$$\therefore h = 14 \times (36)^{\frac{1}{3}}$$

$$= 46.22 \text{ m}$$

The height of 46.22 m required for the effective disposal of the SO_2 and this height is more than the minimum requirement of 30 m height. Hence the height of 46.5 m is

provided for the effective disposal of pollutants including the NO_x, CO and HCs.

Example 2.4 During rush hour on a busy road crossing, nearly 1500 vehicles ply per hour at an average speed of 30 km/hr. Of these, about 80% cars use leaded petrol. The average fuel consumption is one litre for an average of 8 km of travel. Considering that 80% of the lead present in the fuel is emitted in the form of particulate aerosol, find the emission rate of lead aerosol in the ambient air. (Given: concentration of lead in the fuel 0.4 µg/L; assume bright day with Light wind).

◎**Solution:**

Number of vehicles passing per hour on the road = 1500

Since 80% cars use leaded petrol,

the number of lead emitting vehicles
passing per hour on the road, } = 1500 × 80%

$$= 1200$$

Average fuel consumption per hour by each vehicle

$$= \frac{1 \text{ Litre}}{8 \text{ km}} \times 30 \text{ km}$$

$$= 3.75 \text{ litres (L)}$$

Total fuel consumption by 1200 vehicles per hour

$$= 1200 \times 3.75$$

$$= 4500 \text{ Litre/hour}$$

Since the concentration of lead in fuel = 0.4 µg/L

The total lead contained in 4500 L/h of used fuel

$$= 0.4 \mu\text{g/L} \times 4500 \text{ L/hr}$$