CHAPTER 07

Air Pollution

INTRODUCTION

Air is one of the most important constituents of our environment. Even a small concentration of pollutants present in the air becomes more harmful to human health. The clean and pure air, free from outside solid, liquid or gaseous polluting substances (called pollutants), is evidently very essential for human health and survival. Any change in the natural and normal composition of the air (either qualitative or quantitative), that may adversely affect the living system, particularly the human life, invariably causes air pollution.

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

When the quantum of air pollutants exceed the self cleaning properties of the ambient air and start causing harmful effects on the human health and his surrounding abiotic world, then the air is said to be polluted.

Polluted air is also harmful to non living materials like metals, stones, woods, paper etc. These materials gets spoiled by the contact with polluted air either due to physical corrosive action of polluted air or /and due to the chemical attack of the pollutants on such material.

7.1 Source and Classification of Air Pollutants

The air pollutants may be usually classified into groups according to the general nature of source:

(a) Those that come from natural sources which include dust, pollen, fungi spores and smoke from forest fires and volcanic eruptions.

(b) Those that have anthropogenic sources such as originating from combustion, heating processes in industries, manufacturing of chemicals, pulp and paper and petroleum products, food processing and agricultural products.

(c) Aerosols (Particulates): dust, smoke, mists, fog and fumes

(d) Gases and vapours.

Table: 7.1 Classification of pollution		
Major Classes	**Subclasses**	**Typical members of subclasses**
Particulates	Solid Liquid	Dust, smoke, fumes, fly ash Mist, spray
Gases		
Organic	Hydrocarbons	Hexane, benzene, ethylene, methane, butane, butadine
	Aldehydes and ketones	Formaldehyde, acetone
	Other organics	Chlorinated hydrocarbons, alcohols
Inorganic	Oxides of carbon	Carbon monoxide, carbon dioxide
	Oxides of sulfur	Sulfur dioxide, sulfur trioxide
	Oxides of nitrogen	Nitrogen dioxide, nitric oxide
	Oxides inorganics	Hydrogen sulfide, hydrogen fluoride, ammonia

7.1.1 Air Contaminants

Some of these contaminants undergo chemical reactions when they enter the atmosphere. As a result, the end product formed are more harmful than the original contaminants. For example unsaturated hydrocarbons react with nitrogen dioxide in sunlight to form smog.

Table: 7.2

S.No.	Group	Examples
1	Sulphur compounds	SO_2, SO_3, H_2S, Mercaptans
2.	Nitrogen compounds	NO, NO_2, NH_3
3.	Oxygen compounds	O_3, CO, CO_2
4.	Halogen compounds	HF, HCL
5.	Organic compounds	Aldehydes, hydrocarbons
6.	Radioactive compounds	Radioactive gases

7.1.2 Natural Contaminants

7.1.2.1 Aerosols

- The particles larger than a molecules but small enough to remain suspended in air are called aerosols.
- The particulate matter in air may occur in air largely in solid form as particles of dust, smoke, fume etc.
- In form of liquid it is known as mist and fog.

7.1.2.2 Dust

- Dust is made up of small, solid particles created by the breakup of larger masses through processes such as crushing, grinding or blasting may come directly from the processing or handling of materials such as coal, cement or grains.
- It may be a by-product of mechanical process such as the sawing of wood, or made up of residue of mechanical process such as the sawing of wood, or made up of residue of mechanical operation such as sand blasting.
- Capable of temporary suspension in air or other gases, Dusts do not diffuse, they settle under the influence of gravity.
- Dust may range in size from 1 to 1000 μm.

7.1.2.3 Smoke

- Smoke consists of fine, solid particles resulting from the incomplete combustion of organic particles such as coal, wood or tobacco.
- It consist mainly of carbon and combustible materials.
- Smoke particle have diameter ranging from 0.5 to 1 μm.

7.1.2.4 Fumes

- They are fine, solid particles (often metallic oxides such as zinc and lead oxides) formed by the condensation of vapour of solid materials.
- Fumes may be from sublimations, distillation, calcination or molten metal processes.
- They range in size from 0.03 to 0.3 μm.
- Fumes flocculate and coalesce, then settle out.

7.1.2.5 Fly ash

- They consists of finely divided, noncombustile particles contained in flux gases arising from combustion of coal.
- These mineral or metallic substances are released when the organic portion of coal is burned.
- Like dust, it range in size from 1.0 to 1000 μm.
- Like smoke, it result from burning and like fumes, it consist of inorganic metallic or mineral sustenance.

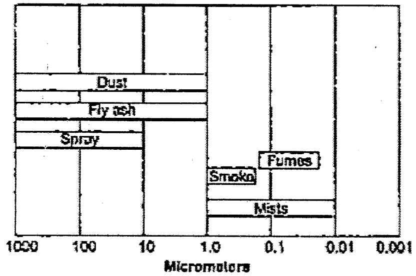


Fig. 7.1 Sizes of particulates in micrometers. (Adopted from Federal Register)

7.1.2.6 Mist

- Mist consists of liquid particles or droplets formed by the condensation of a vapour, the dispersion of a liquid (as in foaming) or the enactment of a chemical reaction such as the formation of sulphuric acid mist.
- Mist are usually less than 10 μm in diameter.
- If mist concentration is high enough to obscure visibility, the mist is called a fog.

7.1.2.7 Spray

- It consists of liquid particles formed by the atomization of parent liquids, such as pesticides and herbicides.
- Spray particles range in size from 10 to 1000 μm.

The total suspended particulate matter (TSPM) in air are indicated below in table 7.3.

Table: 7.3 Types of Particulates in suspended matter			
S. No.	**Term**	**Meaning**	**Examples**
(A)	Liquid particles		
1.	Mist	Aerosols consisting of liquid droplets.	Sulphuric acid mist.
2.	Fog	Aerosols consisting of water droplets.	
(B)	Solid particles		
1.	Dust	Aerosols consisting of solid particles that are blown into the air, or are produced from larger particles by grinding them down.	Dust storm
2.	Smoke	Aerosols consisting of solid particles or a mixture of solid and liquid particles produced by chemical reaction, such as by fires.	Cigarette smoke, smoke from burning of garbage, etc.
3.	Fumes	Generally means the same as smoke, but often used to indicate aerosols produced by condensation of hot vapour of metals.	Zinc/ lead fumes.

7.2 Gases

Following are the gases in air pollutants:

(i) Sulphur Dioxide

- Sulphur Dioxide (SO_2) is the basic air pollutant amongst all the oxides of sulphur.
- SO_2 is an irritant gas, and when inhaled, affects our mucous membranes.
- SO_2 is responsible for causing acidity in fogs, smokes and in rain and hence is the major source of corrosion of buildings and metallic objects.
- The main source of sulphur dioxide is the combustion of fuels, especially coal.
- The major contibutors of SO_2 are refineries, chemical plants, municipal incineration plant etc.

(ii) Carbon Monoxide (CO)

- Carbon monoxide is a colourless, odourless and toxic gas.
- It is produced when organic materials like natural gas, coal or wood are incompletely burnt.
- It is highly poisonous gas and is generally classified as an asphyxiant.
- Chief source of carbon monoxide in the atmosphere is combustion, especially due to automobile exhausts.

(iii) Oxides of Nitrogen (NO_x)

- Atmospheric nitrogen may combine with oxygen at high temperatures, as generated during fuel combustion, to form nitric oxide (NO).
- The nitric oxide (NO) at low levels is relatively harmless but at high concentrations may cause asphyxiation and respiratory discomfort.
- The oxides of nitrogen originates from automobile exhausts, incineration plant, furnace smokes etc.
- Out of seven oxides of nitrogen (N_2O, NO, NO_2, NO_3, N_2O_3, N_2O_4, N_2O_5) only nitric oxide and nitrogen dioxide are classified as pollutants.

NOTE: Oxides of nitrogen becomes more significant, as they are involved in the formations of secondary air pollutants, such as ozone.

(iv) Hydrocarbons (HC)

- They are group of compounds consisting of carbon and hydrogen atoms.
- They are either evaporated into the atmosphere from the petroleum fuel supplies or are emitted out in the automobiles exhausts that did not burn completely. They may also be contained in the fumes of oil refineries.
- HC are washed out of the air when it rains and run into surface water. Their presence in water causes an oily film on the water surface.
- HC are generally divided into two categories i.e.
  - (i) aliphatic group of hydrocarbon
  - (ii) aromatic group of hydrocarbon
- Aldehydes and betones are considered under hydrocarbons, because they are formed by the photochemical occlones of hydrocarbons, as secondary pollutants in the atmosphere.

(v) Hydrogen Sulphide and Mercaptans

- Hydrogen Sulphide is a foul smelling gas.
- The major source of its natural emission include anaerobic biological decay processes an land, in marshes and in the oceans.
- Volcanoes and natural water springs emit hydrogen sulphide to some extent.
- Major sources of hydrogen sulphide is the craft pulp industry.
- The other sulphur compound like mercaptans are important because of their strong odour. The mercaptons are emitted in mixtures of pollutants from some pulp mills, petroleum refineries and chemical manufacturing plants.

(vi) Hydrogen Fluoride

- Hydrogen fluoride is more important in terms of injury to vegetation and animals than in terms of injury to humans.
- HF is an important air contaminant.
- The major sources of fluorides are the manufactures of phosphate fertilizers, the aluminium industry, brick plants, pottery.

7.3 Primary and Secondary Air Pollutants

The natural hazardous events like dust storms, volcanoes etc. or from human activities like burning of wood coal, oil in homes or industries or automobiles etc., are called the primary pollutants. The following five primary pollutants contribute to about 90% of the global air pollution.

The important primary air pollutants are:

(i) Oxides of Sulphur, particularly the Sulphur Dioxide (SO_2)

(ii) Oxides of Carbon like Carbon Monoxide (CO) and Carbon Dioxide (CO_2), particularly the Carbon Monoxide (CO)

(iii) Oxide of Nitrogen, like NO, NO_2 (expressed as NO_x)

(iv) Volatile organic compounds, mostly hydrocarbons

(v) Suspended Particulate Matter (SPM)

(vi) Radioactive Compounds

(vii) Halogen Compounds

Certain less important primary pollutants are Hydrogen Sulphide, Hydrogen Fluoride and other Fluorides.

These primary pollutants react with one another or with water vapour, aided and abetted by the sunlight to form entirely a new set of pollutant called the secondary pollutants.

The import secondary pollutants are:

(i) Sulphuric Acid (H_2SO_4)

(ii) Ozone (O_3)

(iii) Formaldehydes

(iv) Peroxy Acetyl-nitrate (PAN)

(v) Photochemical Smog

Smog:

- Smog is combination of two words smoke and fog. It can be of two types photochemical or coal induced.
- The Photochemical smog is caused by the interaction of some hydrocarbons and oxidants (mainly nitrogen oxides) under the influence of sunlight giving rise to dangerous peroxy acetyl nitrate (PAN).

$$\text{Hydrocarbons} + NO_x \xrightarrow{\text{Sunlight}} \text{Smog}$$

- Its main constituents are nitrogen oxides, PAN, hydrocarbons, carbon monoxide and ozone.
- It reduces visibility, causes eye irritation, damage to vegetable and cracking of rubber.
- Air pollution derived from vehicular emission from internal combustion engines and industrial fumes that react in the atmosphere with sunlight to form secondary pollutants, called modern and that also combine with the primary emission to form photochemical smog.
- Coal induced smog consist of smoke, sulphur compound and fly ash.

7.4 Effects of Air Pollution

- One of the most obvious local effects of particles in the atmosphere is a reduction in visibility.
- The reduction in visibility causes slowdown of air traffic, needing costly instrument guided landing system.
- The presence of gases in the atmosphere has been causing the most prominent effect of producing objectionable odour, taste or obvious corrosive or chemical effects on objects.
- Due to chemical and corrosive effects, the air pollutants have been damaging the exteriors of buildings and cars by breaking down the point emulsion, causing heavy economical losses.
- Due to acidic fumes several monuments have been badly spoiled and damaged.

7.4.1 Effects of Air Pollution on Human Health

- The adverse effect of air pollution on human health has remained the prime consideration in air pollution.
- **Sulphur Dioxide (SO_2)** : SO_2 is an irritant gas which effects mucous membrane when inhaled. It leads to bronchial spasms. Asthma patients are badly affected.
- **Carbon Monoxide (CO)** : CO Carbon Monoxide has a strong affinity for combining with the haemoglobin of the blood to form carboxyhaemoglobin, COHb. This reduce the ability of the haemoglobin to carry oxygen to the body tissues. CO has about two hundred times the affinity of oxygen for attaching itself to the haemoglobin so that low levels of CO can still result in high levels of COHb. Carbon Monoxide also affects the central nervous system.
- **Oxides of Nitrogen** : Among several oxides of nitrogen known to exist in the ambient air, only two are thought to affect human health. These are nitric oxide (NO) and nitrogen dioxide (NO_2). It causes eye and nasal irritation and pulmonary discomfort.
- **Hydrogen sulphide and Mercaptans**: H_2S is a foul smelling gas. It is well known for its rotten egg like odour. Exposures to hydrogen sulphide for short periods can result in fatigue of the sense of smell.
- **Ozone** : O_3 is a gas that has an irritant action in the respiratory track, reaching much deeper into lungs than the oxides of sulphur.
- **Fluorides** : Since fluoride is cumulative poison, hydrogen fluoride is less harmful to human beings.
- **Lead** : The major source of lead in urban atmosphere is the automobile. The effects include gastrointestinal damage of liver and kidney damage, abnormalities in fertility and pregnancy and mental development of children gets affected.
- **Hydrocarbon Vapours** : The effect of it is primarily irritating. It is a major contributor to eye and respiratory irritation caused by photochemical smog.
- **Carcinogenic Agents** : These are responsible for cancer. For example, the poly cyclic organic compound, 3, 4-benzpyrene. The origin of these compounds is in the incomplete combustion of hydrocarbons.
- **Insecticides** : These are not only harmful for insects but also poisonous for human like DDT (Dichloro Diphenyl Trichloroethylene). They can affect the central nervous system and may attack other vital organs. Insecticides/pesticides can also causes premature labour and abortion, due to high concentration of presticides in the body of expectant mothers.
- **Radioactive Isotopes** : The main radioactive isotopes that may reach ambient air and Iodine 131, Phosphorous 32, Cobalt 60, strontium 90, Radium 226, Carbon 14, Sulphur 35, Calcium 45 and Uranium. The serious health effects are anaemia, leukaemia and cancer radioactive isotopes also cause genetic defects and sterility as well as embryo defects and congenital malformation.
- **Allergic Agents** : Allergic Agents are generally recognised by medical personnel that the air we breathe is the natural carrier of many microscopic organic materials which may act as allergens. Our body reactions to such allergens occur mainly in the skin and the respiratory tract.

NOTE: Mercaptans are often added to natural or manufactured gas supplies so that leakage of gas will be noticed.

7.4.2 Effects of Air Pollution on Plants

- The adverse impacts of air pollution are not limited to human health alone but plants are also affected by air pollutants.
- The most prominent air pollutant, which cause severe damage to the plants is fluorine, emitted from factories manufacturing aluminium, glass, phosphate, fertilizers etc. Its concentration in excess of about 0.3 µg/m³ cause photo-toxicological effects on plants.
- The damage caused by the air pollutants like SO_2, H_2F, HC*l*, C*l*$_2$, O_3, NOx, NH_3, Hg, H_2S, H_2N, PAN, herbicides, smog etc., to the plants and vegetation occurs in the leaf structure. The pollutants clog the stomata of the leaf, thereby reducing the intake of CO_2, which adversely affects the photosynthesis.
- Dry Cement-kiln dust appears to cause little damage deposited on a leaf surface, yet in the presence of moisture, such dust imparts damage and consequential growth inhibition to plant tissues.

NOTE

1. Recovery of plant from hydrogen fluoride effect is much slower than SO_2 attack.
2. Chlorine is more toxic to vegetation than SO_2 by a factor of two or three.
3. Hydrogen chloride is considerably less toxic to vegetation than SO_2.

7.4.3 Effects of Air-pollutants on Live Stock Animals

- The adverse health effects of air pollutants on farm animals occur, when animals eat the plants, grasses, fodder and other vegetation, which has been contaminated by the air pollutants.
- Important contaminants that affect the livestock are:
  (i) Fluorine (ii) Arsenic (iii) Lead

Fluorine

(i) It proves to be the worst pollutant since cattle and sheep are found to be more susceptible to consumption of fluorine.
(ii) The cattle grazing on vegetation that has been contaminated with fluorine may develop fluorosis
(iii) Symptoms of advanced fluorosis in animals include: lack of appetites, general ill health due to malnutrition, lowered fertility, reduced milk production and growth retardation.

Arsenic

When such contaminated vegetation is eaten by cattle, they may suffer from arsenic poisoning, with leading symptoms like salivation, thirst, vomiting, uneasiness feeble and irregular pulse and respiration.

Leads

(i) Lead contamination of the atmosphere occurs on account of various industrial sources such as smelters, coke ovens and other coal combustion processes.

(ii) The lead-contaminated vegetation when eaten by live stock animals may cause lead poisoning, which may cause symptoms like inability to stand and staggering, prostration, complete loss of appetite, paralysis of digestive tract and diarrhoea.

7.4.4 Effects of Air Pollutant on Materials and Services

- Air pollutants cause deteriorating effects on metallic surfaces, glass surface, painted surface, building stones, rubber surfaces etc. along with damaging the paper and fabric.
- Oxide of sulphur and nitrogen react in the atmosphere with water vapour to form acidic fumes, which attack and damage the metal surface. This problem is acute for the computer, switch gear and communication industries.
- Fluorine is highly reactive, at high atmospheric concentration, may even cause etching of glass on windows etc.
- Hydrogen sulphide in air reacts with lead oxide in white paint, to form lead sulphate, due to which white painted surface in door, windows, wall in building tend to acquire brownish tint over night.
- Aging of rubber and synthetic fabric due to the atmospheric oxidant, which cause very quick cracking types of rubber and aging and discolourating of synthetic fabrics.
- Electric cables and electricity poles resulting in power leakage from high voltage electric cables. This was caused due to deposition of particles, which are good conductors of electricity or insulator on electrical poles, resulting in leakage from high tension lines.

7.4.5 Effects of Air Pollutant on Aquatic Life

Air pollutant mixing up with rain cause acidity in fresh water lakes, affecting aquatic life, especially the fishes.

7.4.6 Effects of Air Pollutant on Global and Regional Environment

Air pollutants may cause acid rains, ozone depletions and global warming, thereby adversely effecting the environment at regional or global level.

7.5 Photochemical Air Pollution

Photochemical smog is formed due to photochemical oxidation of hydrocarbon and nitrogen oxide.

7.5.1 Nitrogen Dioxide Photochemical Reaction

Ultraviolet light energy is absorbed by NO_2

$$NO_2 + h\nu = NO_2^{*}$$

The highly energized molecule (NO_2^{*}) so formed then decomposes into nitric oxide and atomic oxygen.

$$NO_2^{*} \rightarrow NO + O$$

The atomic oxygen reacts quickly with molecular O_2 to form ozone (O_3)

$$O + O_2 \rightarrow O_3$$

Ozone may also react with NO present to form NO_2 and O_2.

$$O_3 + NO \rightarrow NO_2 + O_2$$

- In the presence of hydrocarbon other reactions take place and aldehydes, peroxides and peroxy acetyl nitrate (PAN) are formed.
- Presence of water vapour may lead to formation of nitric acid (HNO_3) also.

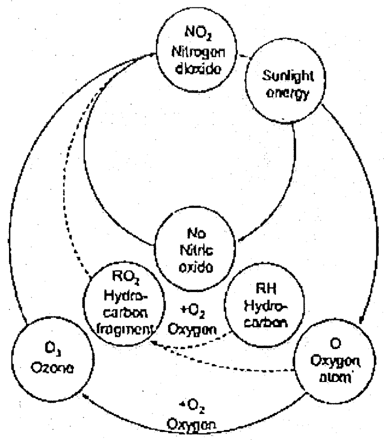


Fig. 7.2 Interaction of atmospheric nitrogen dioxide photolytic cycle with hydrocarbons.

7.5.2 Sulphur Dioxide Photochemical Reaction

Ozone (O_3) may be formed in the atmosphere as a by product during photochemical oxidation of sulphur dioxide to sulphuric acid. However, efficiency of this process is low.

7.5.3 Aldehyde Photochemical Reaction

Photochemical decomposition of aldehydes produces free-radicals and O_3.

Factors affecting photochemical reactions: The nature of photochemical reactions that take place in the atmosphere depends on a number of factors. Some of these factors are:

(i) Light intensity
(ii) Hydrocarbon reactivity
(iii) Ratio of hydrocarbons to nitric oxide
(iv) Presence of light absorbers
(v) Meteorological variables

The height and intensity of atmospheric inversion is also a prime factor.

7.6 Photochemical Smog

Ozone (O_3) and PAN (Peroxy Acetyl Nitrate) are the most significant constituents of photochemical smog

Effects of photochemical smog: There are various effect of Photochemical Smog :

1. Eye irritation - caused by aldehyde, PAN
2. Vegetation damage - caused by O_3, NO_2, and PAN
3. Visibility reduction
4. Cracking of rubber
5. Fading of dyes

7.7 Composition and Structure of the Atmosphere

The atmosphere is conceived mainly of four horizontal (i.e round the globe) layers each characterized by a temperature profile such as.

(a) Troposphere	00 to 11 km	15 to −56°C
(b) Stratosphere	11 to 50 km	−56 to −02°C
(c) Mesosphere	50 to 85 km	−02 to −92°C
(d) Thermosphere	85 to 500 km	−92 to 1200°C

Varying amounts of most of the gases present in the atmosphere may be found in each of the four major layers of the atmosphere.

The air in the troposphere consists of 78 percent nitrogen (N_2), 21 percent oxygen (O_2), 1 percent argon (Ar) and 0.03 percent carbon dioxide (CO_2). Other gases are present in traces, most of which are inert.

7.8 Acid Rain

- The layer of greatest interest in pollution control is the troposphere, since this is the layer in which most living things exist.
- One of the most recent changes in the trophosphere involves the phenomenon of acid rain.
- Acid rain or acid deposition results when gaseous emissions of sulfur oxides (SO_x) and nitrogen oxides (NO_x) interact with water vapour and sunlight and are chemically converted to strong acidic compounds such as sulphuric acid H_2SO_4 and nitric acid HNO_3. These compounds, along with other organic and inorganic chemicals, are deposited on the earth as aerosols and particulates (dry deposition) or are carried to the earth by raindrops, snowflakes, fog or dew (Wet deposition). The effects of acid deposition vary according to the sensitivity of the ecosystems upon which the deposit fall.

NOTE

Generally, 'clean' rain is slightly acidic as it dissolves varying amounts of carbon dioxide. If pH of rain water falls to 5.6 or below then it is called acid rain (the lowest pH value of rain is 5.6 when it is 'clean').

Effects of acid rain: The effects of acid rain deposition vary according to the sensitivity of the eco-systems upon which the deposition fall.

(i) Acid rain has caused considerable damage to buildings and monuments in highly industrialized areas.

(ii) The growth of trees is adversely affected by acid rain. It affects forests and results in consequent vanishing of greenery.

(iii) Acidity also affects soil. A plant nutrient such as potassium is gradually leached out of the soil. At the same time, a toxic element like zinc accumulates due to acid rain. Beneficial micro-organisms in the soil are reduced. The population of earthworms which are popularly called 'farmer friends', is reduced as they cannot tolerate an acidic environment.

Remedy: The problem of acid rain is resolve by neutralising the acid with lime. It is a short-term measure, and it is required to be repeated periodically. But it is quite expensive, especially when areas is large.

7.9 Global Warming

- Our atmosphere has a carbon dioxide concentration of about 0.03 percent. However this concentration is observed to increase continuously due to burning of coal and fossil fuels with increasing use of vehicles etc.
- The effect of increasing concentration of carbon dioxide is the much talked global warming which is known as the green house effect.
- A green house is a construction of transparent walls and roof in cold countries to provide adequate heat to the soil and plants. The solar heat/energy penetrates the green house but is prevented from escaping, and thus heat remains within the green house keeping it warm. A similar process keeping the atmosphere warm is therefore, called the green house effect where mainly carbon dioxide entraps the incoming solar heat.
- Due to the presence of green house gases the heat remains within the atmosphere and does not escape out of it. Thus, the green house gases act like a thermal blanket surrounding the earth.
- Carbon dioxide is the major green house gas which preserves the heat reflected back by the earth's surface. It is obvious that if the concentration of carbon dioxide keeps increasing more and more, heat will be built up in the atmosphere and on the earth's surface back to earth and the atmosphere temperature will increase. This process provides the basic mechanism for global warning.

Green House Gases: The major green house gases are listed as under.

(i) Carbon Dioxide (CO_2)	(ii) Methane (CH_4)
(iii) Nitrous Oxide (N_2O)	(iv) Chlorofluorocarbon (CFC)

(i) Carbon Dioxide:

- It is estimated that the concentration of carbon dioxide in the atmosphere is increasing at the rate of about 1.8 mg/m^3 per year.
- The main factors contributing to the increase in carbon dioxide concentration are : use of fossil fuels deforestation, abuse of land and improper agricultural practices.
- Carbon dioxide absorbs infra red rays causing increase in the heat level. Thus, the increasing concentration of carbon dioxide sets in motion a sort of heat trap.

Do you know? The contribution of carbon dioxide alone towards green house effect is estimated to be about 57 percent.

(ii) Methane

- The methane concentration is increasing at a rate of one percent and its capacity to absorb heat is about 25 times more than that of carbon dioxide. So, although the concentration of methane is very low in the atmosphere, its capacity of absorbing heat is much more. Therefore, it is also an important green house gas.

- Methane is produced as a result of decomposition of organic substances and enters the atmosphere. The role of methane as an agent of green house effect is taken as about 12 percent.

(iii) Nitrous Oxide

- The heat absorbing capacity of nitrous oxide is about 230 times more than that of carbon dioxide, its contribution for green house effect is only 6 percent because of its much lower concentration in the atmosphere.
- The concentration of nitrous oxide increases in the atmosphere due to excessive use of nitrogen fertilizers, increased agricultural activities and intensive vehicular traffic.

(iv) Chlorofluoro Carbon

- The use of chlorofluorocarbon mainly takes place in the industries that manufacture refrigerators, air conditions fire extinguishers, as cleaning solvents in factory, paints and sprays.
- The gas damage the ozone layer that surrounds the globe and allows the short wave radiation to reach the surface of the earth. Thus, the increase of temperature, but by puncturing the ozone layer and consequent happenings.
- Impact of chlorofluorocarbon compared to carbon dioxide is 15000 times and is about 25% responsible for overall green house effect.

Impact of Green House Effect: Some undesirable consequences that may follow global warning is as below:

- The temperature on earth may increase by about 1.5 to 2°C by the year 2050. As a result of increased temperature, the polar ice caps may melt vigorously and there would be rise in ocean level threatening the population near the coastal zones.
- The flora and fauna would also be adversely affected by the increased temperature. Some of the organisms may become extinct as they may not be able to tolerate the high temperatures.
- Human health could, similarly, get affected.
- Sudden changes in the climate, formation of cyclones, stability of seasonal cycles are expected to occur.

7.10 Ozone Layer Depletion

- Ozone layer depletion is the most dreaded aspect of air pollutions, having wide spread implication, extending over the entire atmosphere. This problem is caused by the reduction of naturally available ozone layer in the atmosphere.
- Out of all earlier described zones of the atmosphere, the second zone i.e. the stratosphere, remains the most important to man, as it is the stratosphere which primarily contains ozone gas (O_3) chiefly in the layers between 25 and 40 km above the ground level.
- This ozone layer cut off short wave length radiations (called ultraviolet radiation) from reaching the surface of the earth. Therefore, this process serves as a protective shield to human life against the adverse effects of UV like burn and skin cancer. It is obvious that any depletion of stratosphere ozone would be harmful to life on this earth. Hence ozone layer is termed as ozone umbrella.
- Primary reason for ozone layer depletion is CFC (chlorofluorocarbon) or freons. CFC contains chlorine, fluorine and carbon and it does not occur by itself in nature, but is produced only due to human activities. The freons are a group of cholorofluorocarbons used as aerosol propellants, refrigerants, solvents and as gases for the production of foamed plastics.
- Ozone is destroyed due to the photolytic reaction of CFC as shown below.

$$CFCl_3 \xrightarrow{UV} Cl + \text{other substances}$$

and

$$Cl + O_3 \longrightarrow ClO + O_2$$

- Methane, destroys Cl and thus affords protection to the ozone layer. Similarly, NO_2 reacts with Cl, and helps to prevent the depletion of ozone layer.
- When there is no chlorine present in fluorocarbons, they are called hydrofluorocarbons. These substances are a very important replacement for chlorofluorocarbon because they pose no threat to the ozone layer as they do not contain chlorine.
- As a result of ozone layer, the UV rays do not reach the surface of the earth, and the temperature does not rise. The carbon dioxide in the atmosphere does not allow the release of the reflected solar radiation striking the earth's surface. Thus it protects the heat from being lost out of the global set up. Thus ozone and carbon dioxide both control the temperature on the earth.

NOTE: Vienna convention and Montreal Protocol was concerned with ozone layer depletion.

7.11 Meteorology and Natural Purification Process

Pollution problems arise due to atmospheric contaminants, adverse meteorological conditions or topographical conditions. Because of the close relationship that exists between air pollution and certain atmospheric conditions, it is necessary for the environmental engineer to have a thorough understanding of meteorology.

7.12 Elemental Properties of the Atmosphere

- The source of all meteorological phenomena is a basic, but variable, ordering of the elemental properties of the atmospheric heat, pressure, wind, and moisture.
- All weather, including pressure systems, wind speed and direction, humidity, temperature, and precipitation, ultimately results from variable relationships of heat, pressure, wind, and moisture.

Scales of Motion: The interaction of the four elements mentioned above may be observed on several different levels or scales. These scales of motion are related to mass movements of air which may be global, continental, regional, or local in scope.

According to their geographic range of influence, the scales of motion may be designated as macroscale, mesoscale or microscale.

(i) Macroscale

- Atmospheric motion on the macroscale involves the planetary patterns of circulation, the grand sweep of air currents over hemispheres. These phenomena occur on scales of thousands of kilometers and creates semipermanent high-and low pressure areas over oceans and continents.
- The direction of surface winds is usually controlled by the pressure gradient and rotation of the earth. Because of rotation of the earth along its axis the winds are deflected. The force which deflects the direction of winds is called deflection force
- This force is also called Coriolis force. Because of Coriolis force, all the winds are deflected to the right in the northern hemisphere while they are deflected to the left in the southern hemisphere with respect to the rotating earth.

- The sun's rays heat the earth near the equator to a great extent , the heated air at the equator would rise and cool air from the poles would move in to take place.

(ii) Mesoscale

- Secondary or measoscale, circulation patterns develop over regional geographic units, primarily because of the influence of regional or local topography. These phenomena occur on scales of hundreds of kilometers.
- Air movement on this scale is affected by the configuration of the earth's surface - the location of mountain ranges, oceanic bodies, forestation, and urban development.
- Land fronts, and urban heat islands are typical local phenomena observable on this scale.

(iii) Microscale

- Microscale phenomena occur over areas of less than 10 km and can be exemplified by the meandering and dispersion of smoke plumes from industrial stacks.
- Phenomena of this scale occur within the friction layer, the layer of atmosphere at ground level where effects of frictional stress and thermal changes can cause winds to deviate markedly from a standard pattern.
- The frictional stress encountered as air moves over and around irregular physical surface such as buildings, trees, bushes, or rocks causes mechanical turbulence which influences the pattern of air movement.

NOTE: It is the movement of air on mesoscale and microscale levels that is of vital concern to those with the control of air pollution.

Heat:

- Heat is the critical atmospheric variable, the major catalyst of climatic conditions.
- The heat energy in the atmosphere comes from the sun or shortwave radiation (about 0.5 μm) mostly in the form of visible light
- The earth emits longer wavelengths (average of 10 μm) than it receives, mostly in the form of invisible heat radiation.
- Four important ways in which heat transfer occurs in the troposphere are through the greenhouse, effect, the condensation-evaporation cycle, conduction and convection.

Example 7.1 Convert 120 mg/m³ of SO_2 concentration into ppm at 20°C.

Solution: We know that all gas at 0°C and atmospheric pressure occupies 22.4 litre/mole. i.e. at STP (Standard temperature and pressure)

$$V_1 = 22.4 \text{ litre}$$

$$\text{Volume at } T°C = V_2$$

Now $$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$ [From gas law (temperature is in Kelvin)]

But pressure is always atmospheric

$$\Rightarrow \quad V_2 = \frac{V_1(T_2)}{T_1} = \frac{V_1(273+T)}{273}$$

$$1 \text{ ppm } SO_2 = \frac{1 m^3 \text{ of } SO_2}{10^6 m^3 \text{ of air}}$$

Molecular weight of SO_2 = 64

⇒ 64 g of SO_2 occupies V_2 litre at T°C

$$1 m^3 \text{ of } SO_2 \text{ will have } \frac{64000 \text{ mg}}{V_2} \times 1000$$

$$\Rightarrow \quad 1 \text{ ppm } SO_2 \text{ at } T°C = \frac{64 \times 10^6 \text{mg}}{V_2 \times 10^6 m^3 \text{ of air}}$$

$$\Rightarrow \quad \boxed{1 \text{ ppm at } T°C = \left[\frac{\text{Molecular wt}}{(\text{Volume at } T°C \text{ in litre/mole})}\right] \frac{\text{mg}}{m^3 \text{ of air}}}$$

$$\Rightarrow \quad \boxed{\frac{1 \text{ mg}}{m^3} \text{ of } SO_2 = \left(\frac{\text{Volume at } T°C \text{ in litre/mole}}{\text{Molecular wt}}\right) \text{ppm}}$$

$$\Rightarrow \quad \frac{120 \text{ mg}}{m^3} \text{ of } SO_2 = \frac{120 \times 22.4 \times \frac{273+20}{273}}{64} \text{ ppm} = 45 \text{ ppm}$$

7.13 Control of Air Pollution

The air pollutants in atmosphere are controlled by natural processes as well as by engineered systems wherever necessary.

7.13.1 Natural Self Cleansing Properties of the Environment

- The various natural processes which act as the pollution removal mechanisms in the atmosphere such as dispersion, settling, washout, rainout and adsorption.
- Although dispersion is not really a removal mechanism, it reduces concentration of pollutan's at one place.
- Settling means gravitational settling which removes relatively large particles of diameter than 20 micrometer.
- Washout or scavenging is the natural absorption process where particulates or gaseous pollutants are collected in rain or mist and settle down with that moisture. This process, however does not help in removing particles smaller than 1 μm in size.
- Washout occurs below cloud level.
- Rainout is the process involving precipitation above the cloud level, where submicron particles present in the

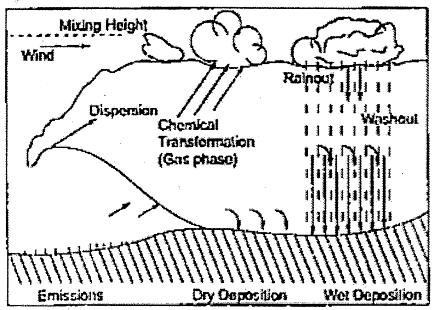


Fig :7.3

atmosphere serve as condensation nuclei, around which drops of water may form and fallout as rain drop.

- Adsorption takes place near the layer of atmosphere closest to the earth's surface. The pollutants solid, liquid or gases are attracted to the surface and retained there.

7.13.2 Engineered System

These are two methods for air pollution control:

(a) Dilution (b) Control at source

(a) Dilution

(i) In tall chimneys, discharge the contaminants at a higher level from ground where they get diluted in the atmosphere.

(ii) This reduces, the concentration of contaminants at ground level.

(iii) The high-rise chimneys spread the emitted smoke over a large area and thus transporting the pollutants over greater distances.

(iv) It is however, obvious that the method does not remove or reduce the pollution load from the total environment, as a whole.

(b) Control at source

(i) Many devices are available to control the pollutants at the very source itself. Various devices are employed depending on the type of pollutants (particulates or gaseous), efficiency that is required and economic factors.

(ii) The pollution at source can also be considerably reduced by adopting one or more of the following strategies:

(a) Changing the location of the industry

(b) Changing the type of the fuel for industry

(c) Changing the process of manufacturing

(d) Maintaining good house keeping

(e) Installation and operation of properly designed air control equipment devices that help in reducing particulate matter and devices that reduce gaseous pollutants.

7.14 Control Devices for Particulates

Most ambient particulate air pollution is caused by stationary sources power plants, industrial processes and incinerations. The primary factors that determine which types of equipment is best suited for a specific application are the average particle size and particle density.

The simplest device is the settling chamber. It is basically an enlarged compartment in which the velocity of the carrier gas is reduced. Thus, the coarse particulates (more than about 40 μm in size) settle out under the action of gravity. A setting chamber of this type best servers as a pre-cleaner to prevent logging of the main small particle collector. Sometimes baffles are added inside the chamber for increased efficiency.

There are a few devices available for controlling atmospheric pollution, in particular for the removal of particulate matter, as described below

(i) Gravitational settling chambers

- These chambers are simple in design, operation, maintenance and register a low pressure loss.
- Like settling basins in water and waste water system, settling chambers in air-pollution-control systems provide enlarged areas to minimize horizontal velocities and allow time for the vertical velocity to carry the particle to the floor.

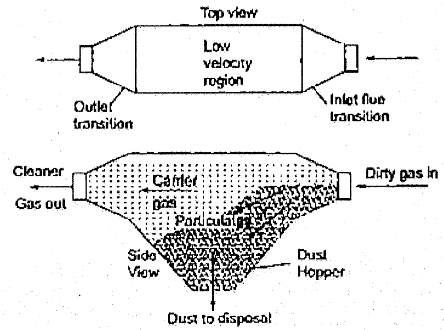


Fig. 7.4

- The usual velocity through settling chambers is usually between 0.5 to 2.5 m/s, but for best results the gas flow should be uniformly maintained at less than 0.3 m/s.
- Only larger sized particles are separated out.
- Although theoretically they should be able to remove particulates down to 5 or 10 μm, but in actual, they are not practical for the removal of particles much less than 50 μm in size. So only larger size particles are separated out.
- Their installation requires larger space while their collection efficiency is less than 50%.

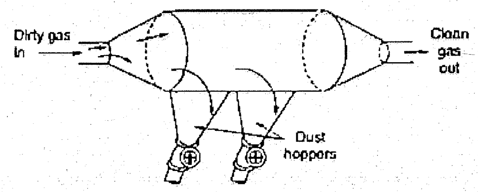


Fig. 7.5 Gravitational settling chamber (Patculate Emission Control Devices)

(ii) Centrifugal Gas Collectors

- Centrifugal collectors employ a centrifugal force instead of gravity to separate particles from the gas stream.
- Instead of gravity chamber, centrifugal collectors can remove particles which are much smaller than those that can be removed in gravity settling chambers.

There are two types of centrifugal collectors

(a) cyclone collectors (or separators)

(b) dynamic precipitators.

(a) Cyclone Collectors

- It consists of a cylindrical shell, conical-base, dust hopper and an inlet where the dust-laden gas enters tangentially.
- This is a closed chamber, in which the inlet velocity of the gas (smoke) is transformed into a spinning vortex, which helps to throw out the particles under the generated centrifugal force. The particles then slide down the chamber walls into the hopper from where they come out.
- The operating or separating efficiency of a cyclone depends on the magnitude of the centrifugal force exerted on the particles. The greater the centrifugal force, the greater the separating efficiency.
- Large-dia. cyclone collectors have good collection-efficiencies for particles 40 to 50 μm in diameter. High-efficiency cyclones with diameters of 23 cm or less have good efficiencies for particles from 15 to 20 μm.

- The cleaning efficiency for units may be as high as 90 percent for particulates in the 5 to 10 μm range.
- It is relatively inexpensive to construct and operate, and they can handle large volumes of gases at temperatures up to 980°C. Pressure drops across these units are generally low and range from 2.5 to 20 cm of water.
- The cyclones have been used successfully at feed and grain mills, cement plants, fertilizer plants, petroleum refineries, asphalt mixing plants and other applications involving large quantities of gas containing relatively large particles.

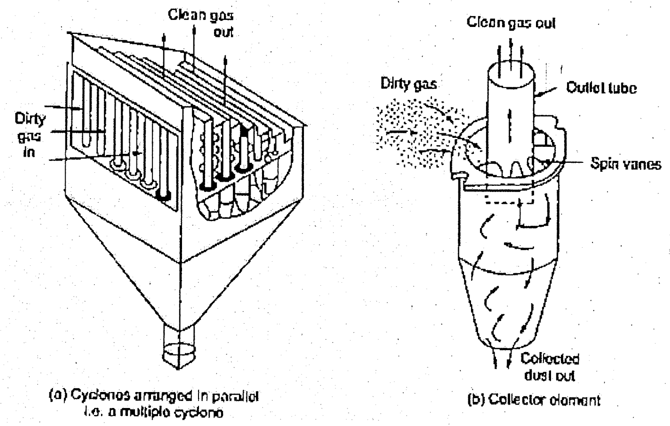


Fig. 7.6 Cyclone collector (Cyclone separator)

(b) Dynamic Precipitations

- Its imparts a centrifugal force to the incoming gas by the means of its rotating vanes.
- This process is about 7 times more effective than the cyclone type.
- This unit can function as an exhaust fan as well as a dust collector.
- These are widely used in ceramics, food and pharmaceutical and wood working industries.
- These machines cannot work with wet fibrous material that may tend to accumulate onto the rotating vanes.

(c) Wet Scrubbers

- In these devices, the particulates from the incoming gaseous stream are removed by allowing the flue gases to flow up against a falling water (liquid) stream.
- In this, particulates mix up with the droplets getting incorporated into them, and then fall down and removed.

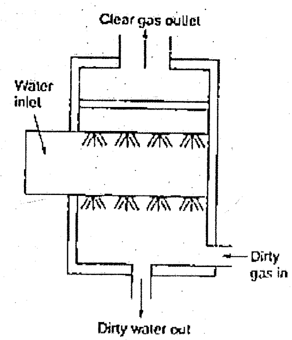


Fig. 7.7 Spray tower (Also used for removing gaseous pollutants).

- When aqueous chemical solutions, other than water, like lime, potassium carbonate (K_2CO_3), slurry of MnO and MgO, etc. are used, we achieve the removal of gaseous pollutants also from the flue gases.
- According to the contact-power theory developed for scrubbers, collection efficiency for well-designed wet collectors of all types is a function of the energy consumed in the air-to-water contact process. The energy consumed is directly proportional to the pressure drops and comparable performance can be expected from all well designed wet collectors operating at or near the pressure drop.
- Cleaning efficiency of wet collectors varies directly with the size of the particulates being collected in addition to the pressure drop.
- Usually, collectors operating at very low pressure loss will remove only medium to coarse size particles, while collectors operating at higher pressure losses (and therefore increased energy output) will be highly efficient at removing fine particles.
- Most commonly used wet collectors for control of particulate matter - the spray tower, the wet cyclone scrubber and the venturi scrubber.

Example 7.2 Assertion (A): Wet scrubber removes particulates from a gaseous stream.
Reason (R): In the wet scrubber water droplets come into contact with the particulates.
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Ans: (a)
Wet scrubber removes gaseous pollutant and particulate matter incorporating them into liquid droplets directly on contact efficiency.

(vi) Spray Towers

- These are low-cost scrubbers that can be used to remove both gaseous and particulate contaminants.
- The units cause very little pressure loss and can handle large volumes of gases.
- Spray Towers are effective in removing particles in excess of 10 μm and modification can be done to improve it for smaller particles.

(vi) Wet Cyclone Scrubbers

- In this scrubbers, high-pressure spray nozzles located in various places within the cyclone chamber generates a fine spray that intercepts the small particles entrained in the swirling gases.
- The particulate matter thrown to the wall is then drained to the collection sump.
- For droplets of 100 μm, efficiency approaches 100 percent and 90 to 98 percent removal is achieved for droplets between 5 and 50 μm.

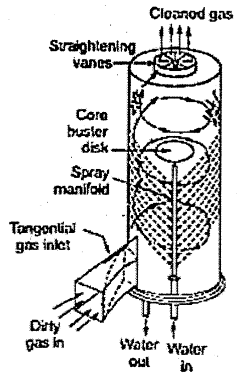


Fig. 7.8 Wet-Cyclone scrubber

- Particle removal depends on contact with the liquid droplets and is a function of the liquid flow rate and liquid droplet and particle sizes.
- Efficiencies slightly higher than those obtained with the spray tower can be expected.

(viii) Venturi Scrubbers

- They are most efficient for removing particulate matter in the size range of 0.5 to 5 μm, that makes them especially effective for the removal of submicron particulates associated with smoke and fumes.
- At velocities from 60 to 180 m/s, the contaminated gas passes through a duct that has a venturi shaped throat section. A coarse water spray is injected into the throat, where it is atomized by the high gas velocities. The liquid droplets collide with the particles in the gas stream, and the water and particles fall down for later removal.

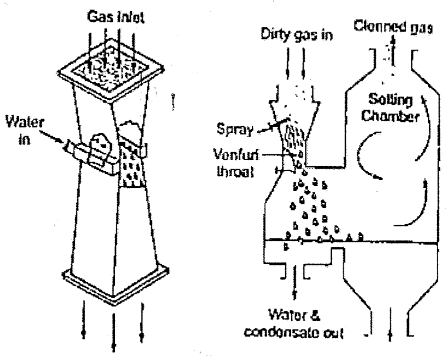


Fig. 7.9 Venturi-scrubber (also used for removing gaseous pollutants)

- They can efficiently remove gaseous as well as particulate contaminants.

(ix) Electrostatic Precipitators

- In this precipitators, the emitted gas (flue gas) is passed through a highly ionised atmosphere (high-voltage field) and there in that zone particulates get electrically charged with the result that they get separated out from the gaseous stream with the help of electrostatic forces.

NOTE: They are extensively used in thermal power plants, pulp and paper industries, mining and metallurgical industries, iron and steel plants, chemical industries, etc.

There are two types of electrostatic precipitates available, such as:

(i) **Low voltage two stage units :** These units operate at 6000 to 12000 V and are commonly used to collect liquid particles. They have a design capacity of 10 m^3/sec for a gas passing with a velocity of 0.5 m/s.

(ii) **High voltage single stage units:** These unit work at 30000 to 100000 V. They are recommended for use in large industrial plants.

There are many advantages associated with electrostatic precipitators as listed below:

(i) Very small particles also, wet or dry can be easily trapped (size about 1 micrometer).

(ii) More than 99% efficiency can be achieved in their functioning (usual range of efficiency is 95 to 99%).

(iii) In this if corrosive and adhesive particles are absent from the gasses, they require a nominal maintenance.

(iv) It have only few moving parts and thus the requirements of repair, etc. is minimal.

(v) They can be operated at high temperature (upto 300 to 450°C).

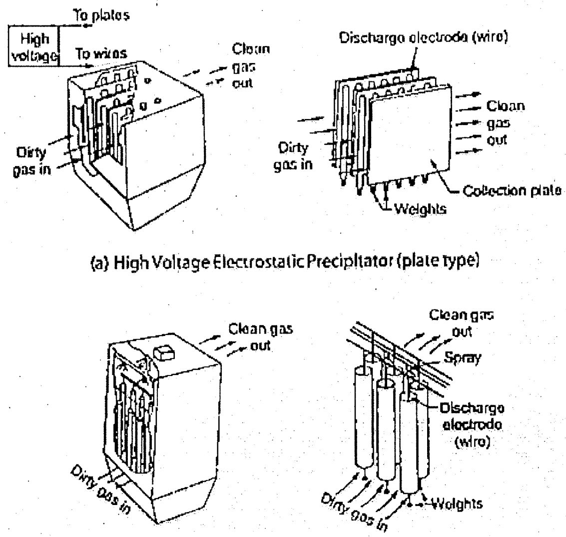
(vi) Pressure drops and power requirement are not very high

There are few disadvantage with these units:

(i) Their installation requires higher initial costs and are sensitive to variable duct loadings and flow rates.

(ii) Working at high voltages poses risks to personal safety and hence precautions are essential.

(iii) The efficiency of collecting pollutants reduces with the passage of time.



(a) High Voltage Electrostatic Precipitator (plate type)

(b) High Voltage Electrostatic Precipitator (tube type)

Fig. 7.10

Example 7.3 Two electrostatic precipitators (ESPs) are in series. The fractional efficiencies of the upstream and downstream ESPs for size d_p are 80% and 65%, respectively. What is the overall efficiency of the system for the same d_p?

(a) 100% (b) 93% (c) 80% (d) 65%

Solution: Given data: $\eta_1 = 80\%$; $\eta_2 = 65\%$

Since the efficiency of upstream Especially is 80%, only 20% of the particulate are not removed. These remaining particulates will face the downstream Especially whose efficiency is 65%.

∴ Particulates removed by downstream Especially $= 20 \times \frac{65}{100} = 13\%$.

The two ESPs are connected in series, therefore the overall efficiency = 80 + 13 = 93%.

(x) Fabric Filters

- In this system, the particulate laden gas stream passes through a woven or felted fabric which filters out particulate matter, allows a gas to pass through it.

- Small particles are initially retained on the fabric by direct interception, inertial impaction, diffusion, electrostatic attraction and gravitational settling.
- After a dust mat has formed on the fabric, more efficient collection of submicron particle (99+ percent) is accomplished by sieving.
- Filter bags usually tubular or envelope shaped are capable of removing most particles as small as 0.5 μm and will remove substantial quantities of particles as small as 0.1 μm.

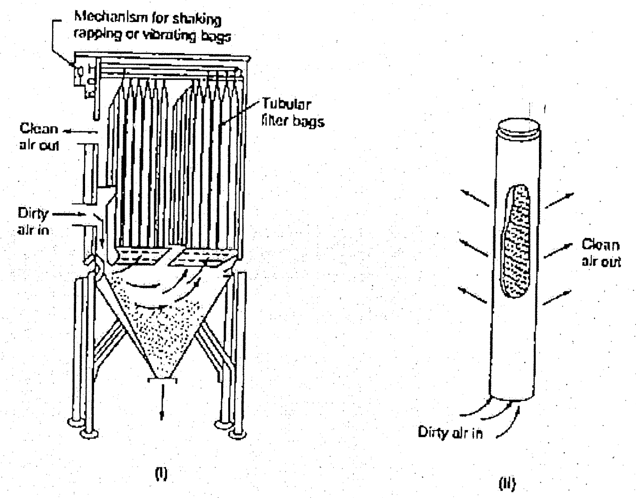


Fig. 7.11 Bag house fabric filter unit

Advantages

- Fabric filter has a high collection efficiency over a broad range of particle sizes.
- Externally flexible in design.
- Ability to handle large volumes of gases at relatively high speeds.
- Reasonable operating pressure drops and power requirements and the ability to handle a diversity of solid materials.
- They are particularly useful in many high volume operations such as cement kiln foundries, steel furnaces and grain handling plants.

NOTE

(i) The possibility of explosion or fire exists if sparks are discharged in a bag house area where organic dusts are being filtered.

(ii) Space limitations may prohibit use of bag house large enough to handle heavy loads.

(iii) There is always a slight possibility of rupture or other adverse effects because of temperature too high for the fabric medium or because of the moisture acidity or alkalinity content of the particulate laden gas stream.

Table No. : 7.4 The methods of control of air pollution has been summarized in tablod form.

S. No.	Name of Mechanical Device	Minimum Particle size that can be removed in μm	Efficiency %	Merits	Demerits	Principle of Working and Uses
1.	Gravitational Settling Chambers	> 50 μm	< 50%	Simple to design and maintain, and low pressure loss.	Requires larger space, and collection efficiency is also low. Only larger sized particles are separated out.	The emitted smokes, when made to pass through a settling chamber, drop some of their larger sized particles in the chamber, under Stoke's law. The largest size particle (d) that can be removed with 100% efficiency in such a chamber of length L and height H is given by equation $d = C\sqrt{\frac{18\mu \cdot v_h \cdot H}{g \cdot L \cdot \rho_p}}$ where v_h = horizontal velocity of gas passing through the chamber between 0.5 to 2.5 m/sec. ρ_p = density of particles removed; μ = viscosity of air, at the given temperature in kg/m.sec; C = correction factor for existing non-quiescent conditions in the gas flow through the chamber, generally taken at equal to 2.
2.	Centrifugal Collectors Including Cyclone collector or separator and Dynamic	5-25 μm	50-90%	Relatively inexpensive simple to design and maintain requires less floor area; ensures dry continuous disposal of collected dusts; low to moderate pressure loss (2.5 to 20 cm); can handle large volumes of gases at temperatures upto 90°C. Cyclones are widely used in industries producing larger quantities of gas containing larger sized particles, like, Cement and Fertiliser plants, Petroleum refineries, Asphalt, mixing plants, Grain mills, Cottongins, etc	Requires much head room; collection efficiency is low for smaller particles, quite sensitive to variable dust loadings and flow rates.	A cyclone collector is a specially designed closed chamber, in which the velocity of the inlet gas is transformed into spinning vortex, and the particles from the gas are thrown out under the centrifugal force. The particles thrown out on the walls of the chamber, slide down to the hopper, and, are thus removed. Its efficiency depends on the generated centrifugal force, which in turn, depends on mass of the particles (M_p), inlet gas velocity(v) and radius of cyclone (R), and is given by the equation F_r = centrifugal force generated. $= M_p \frac{v_t^2}{R}$ A dynamic precipitator imparts centrifugal force to the entering gas with the help of rotating vanes, and is, thus, about 7 times more effective than an ordinary Cyclone. Such a unit can work as an exhaust fan as well as a dust collector. They are widely used in Ceramics. Food and Pharmaceutical, and Wood working industries. They cannot, however, handle wet fibrous material, which tend to accumulate on the moving vanes. A photo view of such a device is shown in fig.

3.	Wet Scrubbers or Collectors, including Spray tower Wet Cyclonic scrubber Venturi Scrubber	> 10 µm > 2.5 µm > 0.5 µm	< 80% < 80% < 99%	(i) The spray tower and venturi scrubber can be made to remove gaseous pollutants also, along with removing particulate matter. (ii) Hot gases can be cooled down. (iii) Corrosive gases can be recovered and neutralized. (iv) The separated gases through contact with aqueous chemicals may produces such useful byproducts as chemical and fertilisers.	(i) A lot of waste water needing disposal may be produced. (ii) Maintenance cost is high, when corrosive materials are collected. (iii) Wet outlet gases cannot rise high from the stack (iv) Poses freezing problems in cold countries. (v) Plume may sometimes be visible in the sky due to the pressure of water vapour.	In these devices, the flue gas is made to push up against a down falling water (liquid) current. The particulate matter mixes up with water droplets and, thus, falls down and gets removed. Water solutions, when replaced with other aqueous chemical solutions, like lime, potassium carbonate, slurry of MnO and MgO, etc. do help in removing gaseous pollutants also from the flue gases.
4.	Electrostatic Precipitators	> 1 µm	95 - 99%	(i) Particles may be collected wet or dry. (ii) 99% and plus efficiency can be obtained. (iii) Even small particles can be removed. (iv) Maintenance is nominal, unless corrosive and adhesive materials are present in flue gases. (v) They contain a few moving parts. (vi) They can be operated at high temperatures upto 300 - 450°C	(i) A lot of waste water needing disposal may be produced. (ii) Maintenance cost is high, when corrosive materials are collected. (iii) Wet outlet gases cannot rise high from the stack. (iv) Poses freezing problems in cold countries. (v) Plume may sometimes be visible in the sky due to the pressure of water vapour.	In electrostatic precipitators, the flue gas is made to pass through a highly ionised zone, where the particles get electrically charged and are separated out from the gas, with the help of electrostatic forces in the powerful electric field. They are widely used in Thermal power plants Pulp and Paper Industries, Mining and Metallurgical Industries, Iron and Steel plants Chemical industries etc.
5.	Fabric Filters	> 1 µm	99%	(i) Fabric filters can give high efficiency, and can even remove very small particles in dry state. (ii) Performance decrease becomes visible, giving prewarning	(i) High temp gases need to be cooled to the range 100-450°C, within which, the filters are stable. (ii) The flue gases must be dry, as otherwise, there is a risk of condensation inside the filter, which can cause clogging.	In such a system, the flue gas is allowed to pass through a woven or felted fabric, which filters out the particulate matter and allows the gas to pass. Small particles are retained on the fabric initially through interception and later on, when a dust mat is formed, the fabric starts collecting particles more efficiently. A bag house filter unit, provided in an ordinary room of the factory, contains several vertically handing fabric cylindrical bags (1.8 to 9 m long), the upper ends of the bags are closed and lower ends are attached to a hopper, where also, the inlet of the flue gas is located. The upward moving gas drops out particulate matter in these bags, which settles down into the hopper, and cleaner gas goes out through the fabric filters. The framework, housing the hanging bags, is provided with an automatic shaking device for cleaning the bags of the collected dust.

7.15 Control Devices for Gaseous Pollutants

- The principal gases of concern in air pollution control are the sulphur oxides (SO_x), carbon oxides (especially CO), nitrogen oxides (NO_x), organic and inorganic acid gases and hydrocarbons (HC). Major treatment processes currently available for control of these and other gaseous emission include adsorption, absorption, condensation and combustion.
- It is not easy to decide which single or combined air pollution control technique to be used for stationary sources.

7.15.1 Adsorption Unit

- The pollution control process of gas adsorption involves passing a stream of effluent gas through a porous solid material (the adsorbent) contained in an adsorption bed.
- The surfaces of the porous solid material attract and hold the gas (the adsorbate) by either physical or chemical adsorption.
- In physical adsorption, the condensation of gases and vapours on solid at temperatures above dew point, depends upon Vander Waals force (an inter molecular attractive force).
- In chemical adsorption or chemisorption gas molecule forms a chemical bond with the adsorbent, and the gas is held strongly to the solid surface by valence force.
- The adsorbent commonly employed are activated carbon, aluminium, silica gel and fullers earth, activated carbon beds can very effectively catch hydrocarbons, H_2S and SO_2. Adsorbent is kept in beds which may be designed as fixed or moving as fluidized beds.

NOTE

(i) Generally the adsorbent, except activated carbon, have a tendency of capturing water before attacking the gaseous pollutants. Thus water may have to be removed from the gas prior to passing through the beds.

(ii) It may be pointed out, that almost all the adsorbents get destroyed at moderately high temperatures : 150°C for activated carbon, 600°C for molecular sieves, 400°C for silica gel and 500°C for activated alumina. Thus, the devices may become inefficient at such high temperature.

Adsorption Equipment: Adsorbers, the device that contain the adsorbent solid through which the effluent gas must pass, can be designed with fixed, moving or fluidized beds.

(i) Fixed bed

- The unit can be a vertical or horizontal cylindrical shell.
- In this unit, activated carbon is arranged on beds or trays in layers, 1.3 cm (0.5 inch) thick in thin bed adsorbers and greater than 1.3 cm (0.5 inch) thick in deep-bed adsorber.
- If more than one bed is used, the beds can be arranged called multiple fixed bed adsorbers.

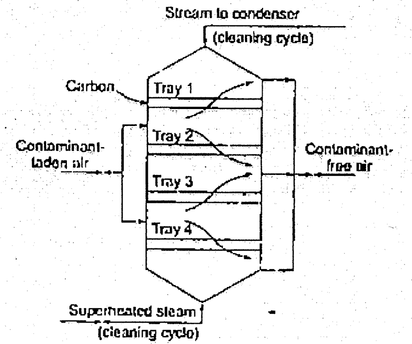


Fig. 7.12 Multiple fixed-bed adsorber

(ii) Moving Bed Adsorber

- In moving bed adsorber unit, the adsorption bed activated carbon is contained in a rotating drum.
- The filtered air containing the gaseous contaminant, is moved by the fan into the rotating drum section.
- The vapour laden air enters ports above the carbon bed, passes through the cylindrical activated carbon bed, enters the space in the inside of this drum, then leaves by ports at the ends of the drum.

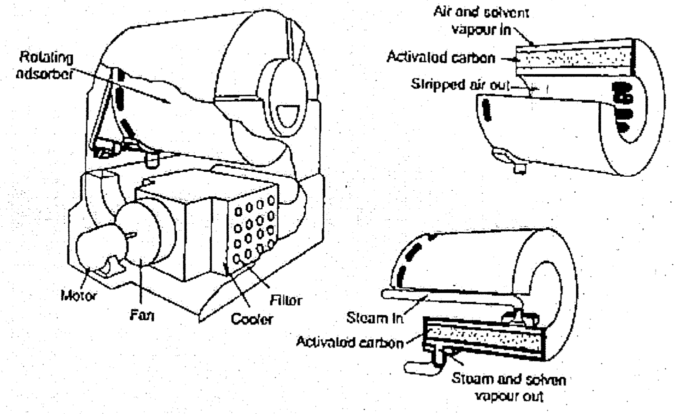


Fig. 7.13 Moving bed adsorber.

(iii) Fluidized Bed Adsorbers

- It contains a shallow, floating bed of adsorbent.
- In this, air flows upward, expanding the bed and suspending or fluidizing the adsorbent.
- The expanding and fluidizing of the adsorbent provides intimate contact between the contaminated gas and the adsorbent and prevents channeling problems often associated with fixed beds.
- Once the gaseous contaminant has been adsorbed, the cleaned air stream passes through a dust collector before being discharged into the atmosphere.

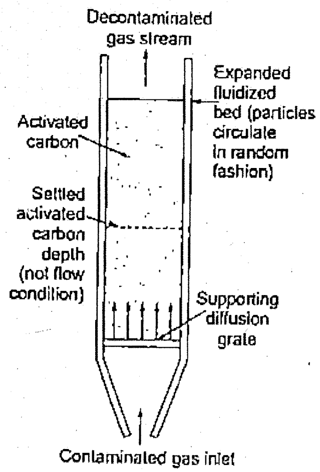


Fig. 7.14 Fluidized adsorber bed configuration

7.15.2 Absorption Units

- Absorption or scrubbing involves bringing contaminated effluent gas (the absorbate or solute) into contact with a liquid absorbent (the solvent) so that one or more constituents of the effluent gas are removed, treated or modified by the liquid absorbent.
- Liquid absorbents may utilize either chemical (reactive) or physical (non reactive) change to remove pollutants. The reactive liquid absorbent (water and limestone) may be used to remove sulphur dioxide from flue gases. When a non reactive absorbent is used, gases are dissolved without chemical change.

NOTE: For effective removal of SO_2, aqueous solutions of alkali and alkaline earths (Na, NH_3, MgO, CaO)

- Absorption units are designed as spray towers, packed towers, tray towers (plate towers) and venturi scrubbers.

(i) Spray Towers

- They can handle fairly large volumes of gas with relatively little pressure drop and reasonably high efficiency of removal as long as gaseous contaminant concentrations are fairly low.
- They are also effective for dual removal of particulate and gaseous contaminants, since they can handle gases with fairly high concentrations of particulates without plugging.
- As smaller the droplet size and greater the turbulence, the more chance for absorption of the gas.
- Since spray towers have much less gas liquid interfacial area than most other types of absorbers, they are generally less effective in removal of gaseous contaminants.

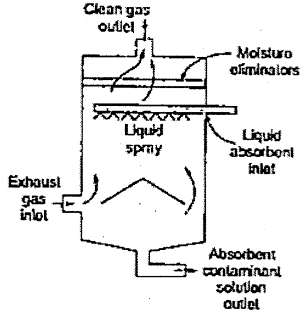


Fig. 7.15 Spray tower
(From control techniques)

(ii) Plate or Tray Towers

- They contain horizontal trays or plates designed to provide large liquid gas interfacial areas.
- In the perforated plate column, the absorbent enters from the side of the column near the top and spills across the top sieve tray. The liquid flows across this trays, over a weir, and to a downpipe that directs the flow to the next tray down. This Zigzag flow continues until the liquid reaches the bottom of the column.
- The polluted air, introduced at one side of the bottom of the column rises up through the openings in each tray and it is the rising gas that prevents the liquid from draining through the openings rather than through the downpipe.

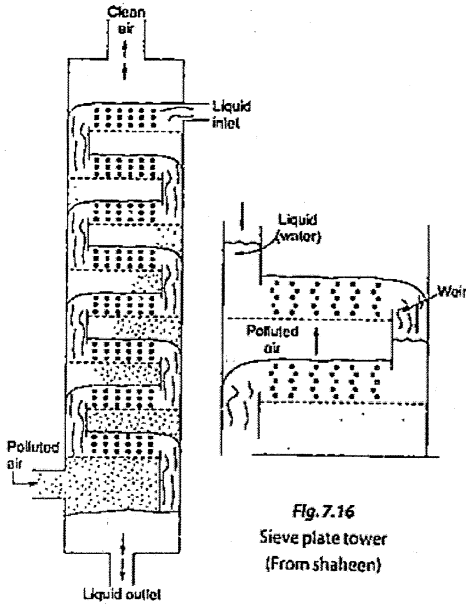


Fig. 7.16
Sieve plate tower
(From shaheen)

- Through repeated contact between air and liquid, gaseous contaminants are removed, and the clean air emerges from the top of the column.

(iii) Packed Towers

- In this tower, packing is used to increase the contact time between vapour and liquid.
- The material chosen for packing has a large surface-to-volume ratio and a large void ratio that offers minimum resistance to gas flow, also are light weight and virtually unbreakable.
- Flow through a packed tower is counter current, with gas entering at the bottom of the tower and liquid entering at the top. Liquid flow over the surface of the packing in a thin film, affording continuous contact with the gases.
- Packed towers become easily clogged when gases with high particulate loads are introduced

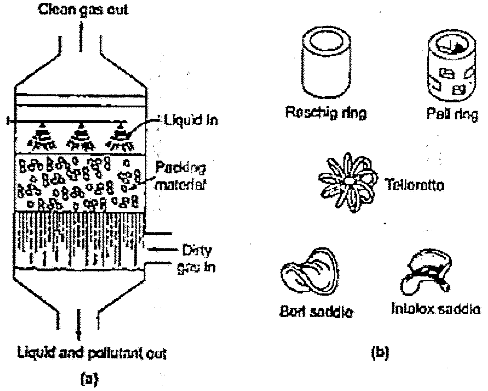


Fig. 7.17 Countercurrent-flow packed tower: (a) tower, (b) packing

(iv) Venturi Scrubbers

- A venturi scrubbers, a cocurrent unit in which the gas and the absorbing solution are brought into contact in or near the venture throat and moved together into an entrainment separator.
- The gas liquid mixture is then separated by the centrifugal force of the liquid droplets as the clean gas stream moves to the exit.
- Venturi scrubbers also remove particulate matter.

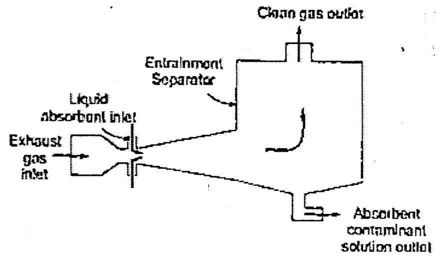


Fig. 7.18 Venturi scrubber

7.15.3 Condensation Units

- A compound will condense at a given temperature if its partial pressure is increased until it is equal to or greater than its vapour pressure at that temperature. If the temperature of a gaseous mixture is reduced to its saturation temperature, its vapour pressure equals its particle pressure and condensation will occur. This is a principle behind this technique.
- Condensation equipment are basically two types — surface and contact condensers.
- In a surface condenser, physical adsorption plays a key role, since contaminants are adsorbed onto a surface as the gaseous compound condenses.
- In a contact condenser, the vapour and cooling medium are brought into direct contact. Contact condenser are less expensive and more flexible than surface condensers, and they are more efficient in removing organic compounds.

NOTE: However, the fact that use of contact condensers can create a water pollution problem some time restricts their use.

- Condensation process, generally considered as pretreatment devices for air pollution control, and condensers are used in conjuction with after burners, absorbers or adsorption units.

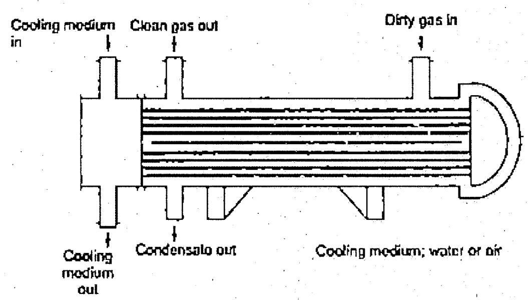


Fig. 7.19 Surface condenser

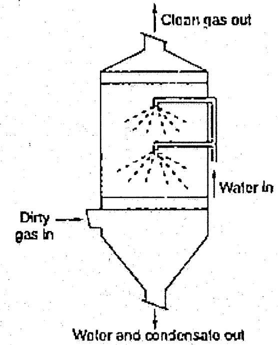


Fig. 7.20 Contact condenser

7.15.4 Combustion Unit

- It is a major source of air pollution, combustion or incineration is also the basis for an important air pollution control process, in which, objective is to convert the air contaminants to innocuous carbon dioxide and water.
- For efficient combustion to occur, it is necessary to have the proper combination of four basic elements oxygen, temperature, turbulence and time.
- The combustion equipment used in it is designed to push oxidation reactions as close as possible to completion, leaving a minimum of unburned compounds.

NOTE: Soot and carbon monoxide are by-products of combustion at low oxidation, while carbon dioxide is a by product of combustion in the presence of sufficient oxygen.

- Depending upon the contaminant being oxidized, direct flame combustion, thermal combustion (after burners) and catalytic combustion methods can be used to control air pollution.

(i) Direct flame combustion

- Here waste gases are burned directly in a combustor with or without the addition of a supplementary fuel.
- In some cases, heat value and oxygen content of the waste gases are sufficient to allow them to burn on their own. In other cases, introducing air and or adding a small amount of supplement fuel will bring the gaseous mixture to its combustion point.
- They are frequently used in petrochemical plants and refineries.

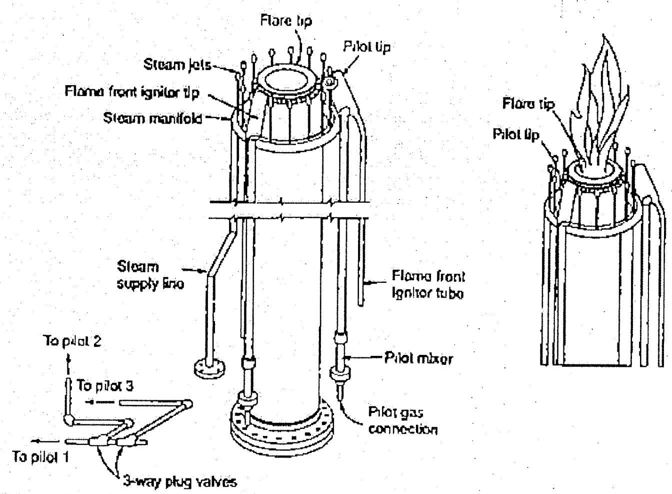


Fig. 7.21 Steam injection type (a) flare, (b) close-up of flare head

(ii) Thermal Combustion

- In cases where the concentration of combustible gaseous pollutants is too low to make a direct flame incineration feasible, in that case, a thermal incinerator or after burner are used.
- The waste gas is preheated, after by use of a heat exchange (a recuperator or regenerator) utilizing heat produced by the thermal incinerator itself.
- The temperature of operations depends upon the nature of the pollutants in the waste gas. Common temperature lie between 538 to 927°C, with operating temperature upto to 1093°C.

NOTE: Thermal after burners must be carefully designed to provide safe efficient operation, since incomplete burning can produce undersirable by products (not only carbon dioxide).

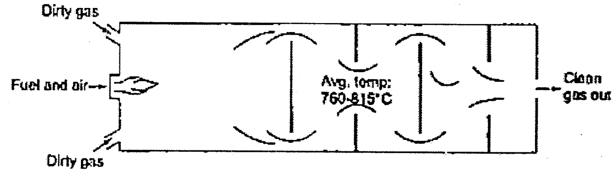


Fig. 7.22 Thermal incinerator

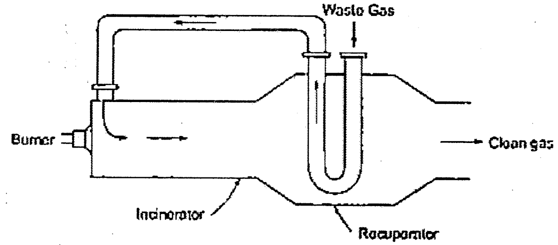


Fig. 7.23 Thermal incinerator with recuperator

(iii) Catalytic Combustion

- A catalyst accelerates the rate of oxidation without itself under going a chemical change, thus reducing the residences, or dwell, time required for incineration.
- They can be used when combustible material in the waste gas are too low to make direct flame incineration feasible.

NOTE: Thermal incineration may require residence times 20 to 50 time greater than catalytic incineration.

- Catalytic combustion processes have been used to control SO_2, NOx, hydrocarbons and carbons monoxide (CO).
- Example of catalysts
  - (i) For removing SO_2 - Vanadium Pentoxide (at high temperature).
  - (ii) For treating NOx - Platinum metals
  - (iii) For hydrocarbons - Activated Alumina
  - (iv) To oxidise CO and CO_2. - Palladium II (Pd II) and Cu (II)

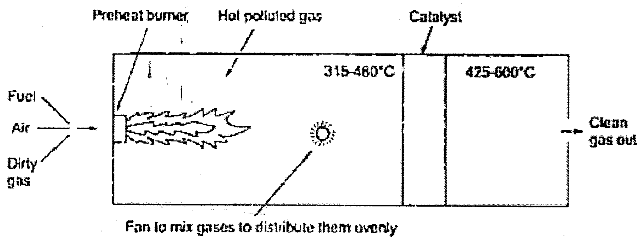


Fig. 7.24 Catalytic incinerator

7.16 Automotive Emission Control

- The chief contents of uncontrolled emissions of an automobile consist of following constituents

CO	0.5 to 6.4%
HC	300 to 1000 ppm
NOx	500 to 3000 ppm

- Emissions from petrol engines contain greater concentrations of HC and CO, while, the four stroke diesel engines (buses and trucks) contain greater concentrations of NO in addition to thick smoke and particulate matter.
- Proper burning of the engine and carburettor helps in the control of pollutant emission.
- Catalytic convertors help in oxidising CO and HC into CO_2. They also reduce NO into nitrogen. These convertors are generally mode of enable metals like platinum, palladium etc. Automobile emissions also possess SO_2 and lead compounds.
- These metal catalysts are very active and they resist sulphur poisoning. They can be used either in form of pellets or as a monolithic one piece metal.
- A catalytic convertor is placed inside the tail exhaust pipe and the emission is allowed into the atmosphere only after passing through this device.
- However, there is some hesitation in using the convertors because they somewhat reduce the efficiency of the engine.

Do You Know?

Maximum permissible carbon monoxide emission while idling
= 3% per cars
= 4.5% for 2 and 3 wheelers

- The Honorable Supreme Court of India, while dealing with the public interest litigation (PIL), has already ordered on 29/04/1999 that all the new cars (petrol as well as diesel driven) to be sold in Delhi and its surrounding towns included in National Capital Region (NCR) must confirm to the stricter international pollution control norms- EURO wef 1/6/1999, and still more stricter norms-EURO II wef 1/4/2000. These Europeans norms are already being followed in advance countries.

7.17 Dispersion of Air Pollutants into the Atmosphere

When once a pocket of smoke, containing air pollutants, is released into the atmosphere from a source like an automobile or a factory chimney, it gets dispersed into the atmosphere into various directions depending upon the prevailing winds and temperature and pressure conditions in the environment.

Lapse Rate: In the troposphere, the temperature of the ambient air usually decrease with an increase in altitude. This rate of temperature change is called the lapse rate. This rate will differ from place to place and from time to time even at the same place.

(i) Environmental lapse rate (ELR)/ Ambient lapse rate: The ELR can be determined by sending up a balloon equipped with a thermometer. The balloon moves through the air, not with it, and the temperature gradient of ambient air, which the rising balloon measures is called the ambient lapse rate, the environmental lapse rate or the prevailing lapse rate.

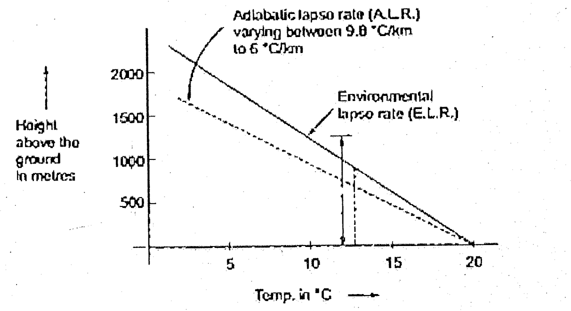


Fig. 7.25 The change of temperature with height in the environment, called ELR

(ii) Adiabatic Lapse Rate

- When a parcel of air, which is hotter and lighter than the surrounding air is released, then naturally it tends to rise up, until of course, it reaches to a level at which its own temperature and density becomes equal to that of the surrounding using the law of conservation of energy and gas law. Therefore, it has been possible to mathematically calculate this rate of decrease of temperature with height, called adiabatic lapse rate.
- A specified parcel of air whose temperature is greater than that of the ambient air tends to rise until it reaches a level at which its own temperature and density equal to that of the atmosphere that surrounds it. Thus, a parcel of artificially heated air (e.g. stack gas or automobile exhaust) rises, expands, becomes lighter and cools. The rate at which the temperature decreases as the parcel gains altitude (the lapse rate) may be considerably different from the ambient lapse rate of the air through which the parcel moves.
- Dry air expanding adiabatically, cools at rate of 9.8°C per kilometer and it is called dry adiabatic lapse rate.
- In wet, as in dry adiabatic process, a saturated parcel of air rises and cools. Temperature changes of the parcel are due to liberation of latent heat as well as of expansion of the air. Wet adiabatic lapse rate (6°C/km) is thus lesser than dry adiabatic lapse rate.
- Since a rising parcel of emitted smokes will normally, neither be fully dry nor fully saturated, the actual adiabatic lapse rate (ALR), representing cooling of the emitted smokes will be somewhere between the dry adiabatic rate (9.8°C/km) and wet adiabatic rate (6°C/km).
- The three major relative position of ELR line with reference to ALR line are discussed below:

(a) Super Adiabatic Lapse Rate

- When the ELR is more than the ALR then ambient lapse rate is super adiabatic and the environment is said to unstable. The atmosphere is said to be unstable as long as a rising parcel of air remain warmer (or descending parcel remains cooler) than the surrounding air, since such a parcel will continue to accelerate in the direction of the displacement.
- Dispersion of pollutants will be rapid due to rapid vertical mixing of the air making the environment unstable.

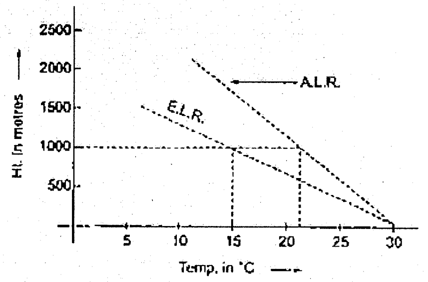


Fig. 7.26

(b) Sub-adiabatic Lapse Rate

- When ELR is less than the ALR the environment set to be stable and this prevailing environmental lapse rate is called the sub-adiabatic lapse rate (as it is less than adiabatic lapse rate).
- When rising parcel of air arrives at an altitude in a colder and denser state than the surrounding air, the resultant downward buoyancy force pushes the displaced parcel of air earthward and away from the direction of displacement.

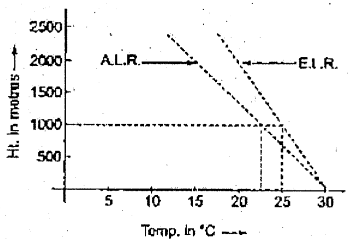


Fig. 7.27

- Under such condition, the atmosphere is said to be stable.

(c) Neutral

- When ELR equals the ALR and both the lines coincide the environment in such a case is called neutral.

7.18 Negative Lapse Rate and Inversion

- When the temperature of the environment (i.e ambient air) increases with altitude then the lapse rate becomes inverted or negative from normal state.
- Negative lapse rate occurs under conditions usually referred to as inversion (a state in which the warmer air lies over the colder air below).
- Such situation may occur near the earth's surface or at greater height in the troposphere but the inversion of temperature near the earth's surface is of very short duration because the radiation of heat from the earth's surface during daytime warms up the cold air layer which soon disappears and temperature inversion also disappears.

NOTE: Such temperature inversion represents a highly stable environment.

There are two types of inversions:

1 Radiation inversion 2. Subsidence inversion

7.18.1 Radiation Inversion

- Radiation Inversion is a phenomenon occurring from the unequal cooling rates for the earth and the air above the earth.
- In other words, when the earth cools rapidly and more quickly than the air above it, then naturally the temperature in the environment will be less at the earth and will increase above it, causing negative lapse rate and inversion conditions.

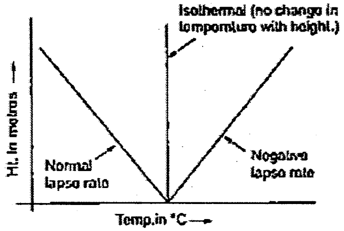


Fig. 7.28

- This type of inversion may extends a few hundred meters into the friction layer and is characteristically a nocturnal phenomenon that is likely to break up easily with the rays of morning sun.
- Such an inversion in the environment, helps in formation of fog when air is wet and simultaneously catches gases and particulate matter, as it stops their upward lifting thereby creating concentration of pollutants in our close environment.
- It is also called ground surface inversion.

7.18.2 Subsidence Inversion

- This is usually associated with a high pressure system and is caused by the characteristic sinking or subsiding motion of air in a high pressure area. i.e. anti cyclones.
- Such inversion layers may be formed from the ground surface to around 1600 m or so.
- It is also called mechanical inversion.

NOTE: Sometimes, both the radiation as well as subsidence inversion may occur simultaneously, causing what is known as double inversion.

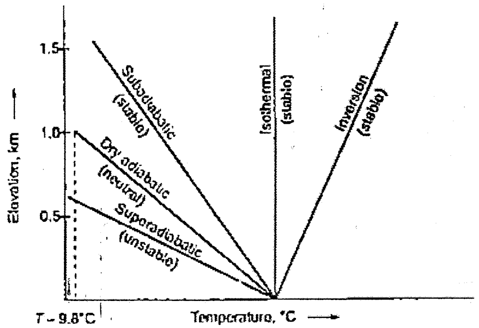


Fig. 7.29 Relationship of the ambient lapse rates to the dry adiabatic rate

7.19 Impact of Winds on Dispersion of Pollutants

- The moving air is known as wind. Such a movement in the air is caused by the unequal distribution of atmospheric temperature and pressure over the earth's surface and is largely influenced by the rotation of the earth. The direction of winds is always from high pressure areas to low pressure areas, but the Coriolis force tends to deflect the air currents out of these expected patterns.

- Regional and local geographical and topographical features may also affect the direction and speed of winds.
- The quicker heating and cooling of the earth as compared to the neighbouring sea, may also cause the flow of sea breezes (from sea to land) during day time and flow of land breezes (from land to sea) during nights after sun-set respectively. Such a wind pattern may also contribute to air pollution problems.
- In the friction layer (zone of atmosphere beneath 700 to 1000 m above the earth surface) at the earth's surface, wind are generally gusty and changeable, primarily due to locally generated mechanical or thermal turbulence.
- Speed is usually measured by an anemometer at a height say Z, knowing the wind velocity (U_0) at anemometer height (Z_0), velocity u at any other height Z by using the formula.

$$u = U_0\left[\frac{Z}{Z_0}\right]^k$$

Where k is a constant 1/9 for large lapse rates and 1/3 for marked inversions, average normal value being 1/7.

- The direction and speed of surface winds primarily govern the drift and diffusion of polluted gases and particulate emission from automobiles and factories etc. emitted near the ground levels. The higher the wind speed at or near the point of emission, the more rapidly the pollutants would be carried away from the source.
- Gustiness which is directly proportional to the wind speed is another important characteristic of surface winds and determines the extent to which the pollutants are mixed and diluted with the ambient air.

NOTE: Wind speed and the concentration of pollutant, both are inversely proportional to each other.

7.20 Plume Behaviour

- Plume can be defined as the path taken by continuous discharge of gaseous effluents emitted from a chimney or stack. The shape of the path and the concentration distribution of gaseous plumes depends upon localized air stability.
- Typical types of environmental conditions, characterised by different relative positions of environmental lapse rate and adiabatic lapse rate lines, which are generally encountered in the lower atmosphere (less than 300 m above the ground). The manner in which the emitted plume behavior are mentioned below.

(i) Looping plume

- Looping plume has wavy character and occurs in super adiabatic environments which produces highly unstable atmosphere, because of rapid mixing. (Fig. 7.30)
- High turbulence helps in rapid dispersion of the plume, but high concentration touch the ground.

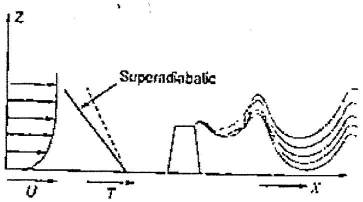


Fig. 7.30 Looping Plume

(ii) Neutral plume

- Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the ELR is equal to ALR. (Fig. 7.31)
- The upward lifting of the plume will continue till it reaches an air of density similar to that of the plume itself.
- The neutral plumes tend to cone, when the wind velocity is greater than 32 km/h and when cloud cover blocks the solar radiation by day and terrestrial radiation by night.

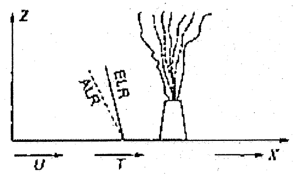


Fig. 7.31 Neutral Plume

(iii) Coning plume

- Conning plume occurs under sub-adiabatic conditions.
- The plume dispersion is known as coning, because the plume makes a cone like shape about the plume line.

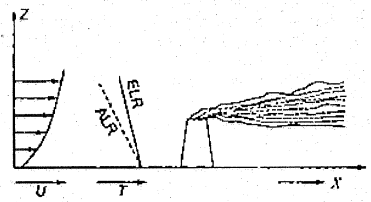


Fig. 7.32 Conning plume

(iv) Fanning plume

- Under extreme inversion conditions in the presence of light wind, fanning plume occurs.
- These will be no vertical mixing and the plume will extend horizontally over large distances. Such a plume pattern is called a fanning plume. (Fig. 7.33)

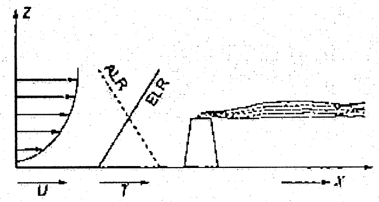


Fig. 7.33 Fanning plume

(v) Lofting plume

- Where there exists a strong super adiabatic lapse rate above a surface inversion, then the plume is said to be lofting.
- Such a plume has minimum downward mixing as its downward motion is prevented by inversion, but the upward mixing will be quite turbulent and rapid. The dispersion of pollutants will therefore, be rapid and no concentration will touch the ground. Hence, this would be the most ideal case for dispersion of emission Fig. 7.34.
- Lofting is the most favourable plume type as far as ground level concentrations and is one of the major goals of tall-stack operation.

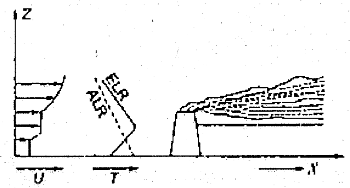


Fig. 7.34 Lofting plume

(vi) Fumigating Plume

- When an inversion layer occur at a short distance above the top of the stack and super adiabatic conditions prevail below the stack, then the plume is said to be fumigating.

- The conditions for fumigation are just the inversion of lofting plume.
- The pollutants cannot escape above the top of the stack because of inversion layer and they will be brought down near the ground due to turbulence in the region above the ground and below the inversion, caused by strong lapse rate.
- This represents worst case of atmospheric conditions for dispersion.

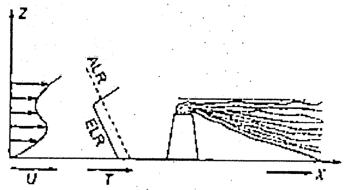


Fig. 7.35 Fumigating plume

(vii) Trapping Plume

- When inversion layers occurs above the emission source, as well as below the source, then naturally, the emitted plume will neither go up, nor will it go down and would remain confined between the two inversions.
- Such a plume is called a trapping plume and is considered a bad condition for dispersion, as the dispersion cannot go above a certain height.

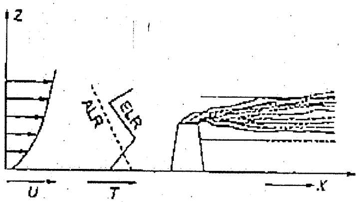


Fig. 7.36 Trapping plume

Example 7.4: From the data given in above example, determine the ground level concentrations at a distance of two km downwind at (a) The centre line of the plume, and (b) at a crosswind distance of 0.5 km on either side of the centre line.

Solution:

(a) Concentration at x = 2 km along centre line of plume, means $y = 0$ and x = 2 km. This concentration is given by equation as:

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

where, σ_z = 130 (for x = 2 km and C class)

σ_y = 220 (for x = 2 km and C class)

$$\therefore \quad C_{(2,0)} = \frac{163.19}{3.14 \times 8 \times 130 \times 220}(e) - \frac{80^2}{2 \times (130)^2} \text{gm/m}^3$$

$$= 2.27 \times 10^{-4} \times (e)^{-0.189} \text{ gm/m}^3 = 2.27 \times 10^{-4} \times \frac{1}{(e)^{0.189}} \text{ gm/m}^3$$

$$= 2.27 \times 10^{-4} \times \frac{1}{1.208} \text{ gm/m}^3 = 1.878 \times 10^{-4} \text{ gm/m}^3$$

$$= 1.878 \times 10^{-4} \text{ gm/m}^3 = 187.8\ \mu \text{ gm/m}^3$$

(b) Concentration at x = 2 km and y = 0.5 km (i.e., 500 m) is given by equation as:

$$C(x, y) = \frac{Q}{\pi U \cdot \sigma_z \cdot \sigma_y} \cdot (e)^{-\frac{H^2}{2\sigma_z^2}} \cdot e^{-\frac{y^2}{2\sigma_y^2}}$$

$$= \frac{163.19}{3.14 \times 8 \times 130 \times 220}(e)^{-\frac{80^2}{2\times(130)^2}} \times (e)^{-\frac{(500)^2}{2(220)^2}} \text{ gm/m}^3$$

$$= (1.878 \times 10^{-4}) \cdot (e)^{-2.583} \text{ gm/m}^3 = 1.878 \times 10^{-4} \times 0.0755 \text{ gm/m}^3$$

$$= 0.142 \times 10^{-4} \text{ gm/m}^3 = 14.2\ \mu \text{ gm/m}^3$$

7.21 Design of Stack Height

Considering the Gaussian plume model with a number of assumption and such variable factors, Central Board for prevention and control of water pollution (New Delhi), through its publication: Emission Regulation (July 1984) as well as under its publication titled "A Method to Determine Chimney Height"

(*i*) For chimney emitting particulate matter

$$h = 74(Q_p)^{0.27} \text{ (height in meter)}$$

where, h = height of chimney

Q = particulate matter emission (tonnes/hours)

(*ii*) For chimney emitting SO_2

$$h = 14(Q_s)^{1/3} \text{ (height in meter)}$$

where, Q_s = SO_2 emission (kg/hour)

(*iii*) Minimum Values

The board has specified that the calculated chimney height for a given particulate matter and SO_2 emissions by the above two equations should be subject to the following minimum values.

(i) For chimney adopted for industries in general (except thermal power plants) - 30 m

(ii) For thermal power plants above 200 MW and below 500 MW capacity 220 m

(iii) For thermal power plants having greater than 500 MW capacity 275 m

Effective Height of a Stack

The value of H used in equation is the effective height of the stack (chimney) and not its actual height. This effective height consists of actual height (h) plus the height (Δh) to which the plume rises above the stack before levelling out, as shown in figure.

$$\therefore \quad H = h + \Delta h \quad \text{...(i)}$$

Where, h = actual height of stack in m

Δh = Plume height in m

There exists several equations for calculating the plume height Δh; out of which, Holland's equation is often used.

$$\Delta h = \frac{v_s D}{u}\left[1.5 + 2.68 \times 10^{-3} P D\left(\frac{T_s - T_a}{T_s}\right)\right] \quad \text{...(ii)}$$

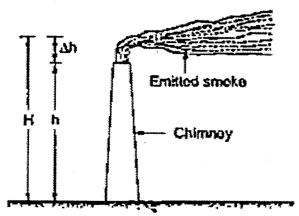


Fig. 7.37

Which Δh = rise of plume above the stack in m

v_s = stack gas velocity i.e., efflux emission velocity from the stack in m/sec

D = inside exit dia. of stack in m

u = wind speed in m/sec

P = atmospheric pressure in milli-bars

T_s = stack gas temperature in °K

T_a = air temperature in °K

Equation (*ii*) is quite suitable for computing Δh from neutral conditions. For unstable conditions, the above value of Δh should be increased by 10 to 20%, and for stable conditions, it should be decreased by 20 to 10%.

Another frequently used equation for computing Δh is given by Davidson and Brayant, as

$$\Delta h = D\left(\frac{v_s}{u}\right)^{1.4}\left(1+\frac{T_s - T_a}{T_s}\right) \qquad \ldots(iii)$$

All the terms used in this equation have the same meaning as for equation (*ii*)

The Bureau of Indian Standards (BIS), earlier known as ISI, has, through their code No. IS : 8829—1978 suggested the following empirical formulas for computing plume rise (Δh):

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

$$\Delta h = 0.84(12.4 + 0.09h)\frac{Q_H^{1/4}}{u} \qquad \ldots(iv)$$

Where Q_H = heat release in calories per second, h and u have the same meaning as for equation (*i*) and (*ii*)

(b) For not very hot releases, and which can be counted as momentum sources above

$$\Delta h = \frac{3v_s D}{u} \qquad \ldots(v)$$

Where v_s and D have the same meaning as above.

Example 7.5 **Determine the effective height of a stack, with the following given data:**

(a) Physical stack is 180 m tall with 0.95 m inside diameter.

(b) Wind velocity is 2.75 m/sec

(c) Air temperature is 20°C

(d) Barometric pressure is 1000 millibars

(e) Stack gas velocity is 11.12 m/sec

(f) Stack gas temperature is 160°C

Solution:

The given data is symbolised as below:

h = 180 m $\qquad D$ = 0.95 m $\qquad u$ = 2.75 m/sec

T_a = 20°C = 20 + 273 = 293 K $\qquad P$ = 1000 millibars $\qquad v_s$ = 11.12 m/sec

T_s = 160°C = 160 + 273 = 433 K

Using equation, we have

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

$$= \frac{11.12 \times 0.95}{2.75}\left[1.5 + 2.68 \times 10^{-3} \times 1000 \times 0.95 \times \frac{433 - 293}{433}\right]$$

$$= \frac{11.12 \times 0.95}{2.75}\left[1.5 + \frac{2.68 \times 0.95 \times 140}{433}\right] = 8.92 \text{ m}$$

or $\qquad \Delta h$ = 8.92 m

H = Effective height of stack

$\therefore \qquad = h + \Delta h$ = 180 + 8.92 = 188.92 m

Illustrative Examples

Example 7.6 A factory uses 1.5 ML of fuel oil per month. The exhaust gases from the factory contain the following quantities of pollutants per ML per year.

(i) Particulate matter = 4 t/year

(ii) SO_2 : 20 t/year

(iii) NOx : 5 t/year

(iv) HC, CO and other : 3 t/year

Determine the safe height of the chimney required for the safe dispersion of the pollutants

Solution:

The concentrations of NOx, HC, CO and others are generally very much less than the concentration of SO_2 in various industries. Hence the Board has made only SO_2 as the criterion for design, along with the particulate matter.

(a) Height of chimney on the basis of particulate matter.

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

Particulate matter emission = 4(1.5 × 12) = 72 t/year

Assuming 300 working days in a year, and 24 hours working a day,

$$Q_p = \frac{72}{300 \times 24} = 0.01 \text{ t/hour}$$

$$h = 74\,(0.1)^{0.27} = 21.34 \text{ m}$$

(b) Height of chimney on the basis of SO_2

$$h = 14(Q_s)^{1/3}$$

Now, $\qquad SO_2$ emission = 20(1.5 × 12) = 360 t/year

$$\therefore \qquad Q = \frac{360}{300 \times 24} = 0.05 \text{ t/year} = 50 \text{ kg/hr}$$

$$\therefore \qquad h = 14(50)^{1/3} = 51.58 \text{ m}$$

$\therefore$ Required height of chimney = 52 m (maximum of 21.34 m and 51.58 m)

Important Expressions

1. Largest size particle (d) that can be removed 100% efficiency in such a chamber of length L_x and height H is given by

$$d = C\sqrt{\frac{18\mu V_h \cdot H}{gL\rho_r}}$$

2. Predicting pollutant concentration through Dispersion models and equation.

$$C = \frac{Q}{kU\sigma_z \cdot \sigma_y} \cdot e^{-\frac{1}{2}\left(\frac{H^2}{\sigma_z^2} + \frac{y^2}{\sigma_y^2}\right)}$$

where, C = concentration of pollution (gm/m³), Q = pollutant emission rate gm/sec, u = mean wind velocity (m/sec), x and y = downwind and crosswind horizontal distance (m).

σ_z = plumes standard deviation in (m), H = effective height of stock

3. Effective Height of Stock

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

where, Δh = rise of plume above stock (m), V_s = stock gas velocity
D = inside exit diameter of stock (m), u = wind speed (m/sec)
T_s = stock gas temperature in k, T_a = air temperature
P = atmospheric pressure in milli-bars

Plume Rise (Δh) → BIS suggested the following empirical formulas

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

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

where, Q_H = Heat release in calories

(b) For not very hot release and which can be counted as momentum sources above

$$\Delta h = \frac{3V_s \cdot D}{u}$$

4. Minimum Chimney Height

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

where, Q_p = particulate matter emission in tonne/hr, h = Chimney Height (m)

(2) $$h = 14(Q_s)^{1/3}$$

where, Q_s = SO_2 emission in kg/hr

Summary

- Duct, smoke, mist, fog and fumes comes under Aerosol (particulate) type of air pollutants.
- SO_2 is one of the principal constituents of air pollutants and major contributors of SO_2 are refineries, chemical plants, municipal in cineration plants etc.
- CO is a highly poisonous gas and is generally classified as an asphyxiant.
- Photochemical smog is caused by the interaction of some hydrocarbons and oxidants (mainly Nitrogen oxides) under the influence of sunlight giving rise to dangerous peroxy acetyl nitrates (PAN)
- Acid rain results when gaseous emissions of Sulphur oxide (SOx) and nitrogen oxide (NOx) interact with water vapour and sunlight and are chemically converted to strong acidic compounds (H_2SO_4 and HNO_3) along with other organic and inorganic chemicals.
- The Green house gases act like a thermal blanket surrounding the earth as due to the presence of green house gases the heat remains within the atmosphere and does not escape out of it.
- Electrostatic precipitators are extensively used in thermal power plants, pump and paper industries, mining and metallurgical industries, iron and steel plants, chemical industries etc.

Objective Brain Teasers

Q.1 Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I
A. CO
B. CO_2
C. SO_2
D. NO_x

List-II
1. Greenhouse effect
2. Acid rains
3. Acute toxicity
4. Ozone liberation at ground level

Codes:

	A	B	C	D
(a)	3	2	1	4
(b)	2	3	4	1
(c)	3	1	2	4
(d)	4	1	2	3

Q.2 The atmosphere extends upto a height of 10,000 km. It is divided into the following four thermal layers:

1. Mesosphere 2. Stratosphere
3. Thermosphere 4. Troposphere

The correct sequence of these starting from the surface of the earth upwards is

(a) 2, 4, 1, 3 (b) 4, 2, 1, 3
(c) 4, 2, 3, 1 (d) 2, 4, 3, 1

Q.3 Which of the following air pollutants is/are responsible for photochemical smog?

1. Oxides of nitrogen
2. Ozone
3. Unburnt hydrocarbons
4. Carbon monoxide

Select the correct answer using the codes given below:

(a) 1 alone (b) 2, 3, and 4
(c) 1, 3 and 4 (d) 1 and 3

Q.4 Match List-I (Equipment) with List-II (Pollutants removed) and select the correct answer using the codes given below the lists:

List-I
A. Electrostatic precipitators
B. Cyclones
C. Wet scrubbers
D. Adsorbers

List-II
1. Coarse particles
2. Fine dust
3. Gas
4. Sulphur dioxide

Codes:

	A	B	C	D
(a)	1	2	3	4
(b)	2	1	3	4
(c)	2	1	4	3
(d)	1	2	4	3

Q.5 Match List-I (Pollutants) with List-II (Sources) and select the correct answer using the codes given below the lists:

List-I
A. Acid water
B. SO_2
C. CO
D. Fly ash

List-II
1. Volcanoes
2. Automobiles
3. Thermal power station
4. Mining

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	4	1	3	2
(c)	1	4	3	2
(d)	1	4	2	3

Q.6 Aerosol is

(a) carbon particles of microscopic size
(b) dispersion of small solid or liquid particles in gaseous media
(c) finely divided particles of ash
(d) diffused liquid particles

Q.7 Match List-I (Air pollutant) with List-II (Environmental effect) and select the correct answer using the codes given below the lists:

List I

A. Carbon monoxide
B. Particulate matter
C. Nitrogen oxides
D. Sulphur dioxide

List-II

1. Respiratory distress for living beings
2. Chemical reaction with haemoglobin in blood
3. Reduction in visibility and aeroallergens carrier
4. Photochemical smog in atmosphere

Codes:

	A	B	C	D
(a)	2	3	1	4
(b)	3	2	4	1
(c)	2	3	4	1
(d)	3	2	1	4

Q.8 If carbon monoxide is released at the rate of 0.03 m^3/min from a gasoline engine and 50 ppm is the threshold limit for an 8 hour exposure, the quantity of air which dilutes the contaminant to a safe level will be

(a) 60 m^3/min (b) 600 m^3/min
(c) 60 m^3/s (d) 600 m^3/s

Q.9 Which one of the following plume behaviours occurs when atmospheric inversion begins from the ground level and continues?

(a) Looping (b) Fumigation
(c) Coning (d) Fanning

Q.10 Which one of the following pollutants or pairs of pollutants is formed due to photochemical reactions?

(a) CO alone (b) O_3 and PAN
(c) PAN and NH_3 (d) NH_3 and CO

Q.11 In the context of basic concept of an ecological system, the most appropriate definition of ecology is that it is a study of the

(a) interrelationship between organisms and the environment
(b) relationship of human species with the industry
(c) relationship of human species with natural resources
(d) relationship of human species with air

Q.12 Organisms that mineralize organic matter in an ecosystem are called

(a) producers (b) consumers
(c) decomposers (d) carnivorous

Q.13 Consider four common air pollutants found in urban environments, NO, SO_2, Soot and O_3. Among these which one is the secondary air pollutant?

(a) O_3 (b) NO
(c) SO_2 (d) Soot

Q.14 Which of the following air pollutants are responsible for the greenhouse effect?

1. Methane
2. Carbon dioxide
3. Chlorofluorocarbons
4. Nitrogen oxides

Select the correct answer using the codes given below:

(a) 2 and 3 (b) 1 and 2
(c) 1, 3 and 4 (d) 1, 2, 3 and 4

Q.15 Which of the following pairs are correctly matched?

1. Ringelmann chart : To grade density of smoke
2. Pneumoconiosis : Disease caused due to coaldust
3. PAN : Secondary air pollutant

Select the correct answer using the codes given below:

(a) 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 1, 2 and 3

Q.16 Elevation and temperature data for places are tabulated below:

Elevation 'm'	temp. °C
4	21.25
444	15.70

based on data, lapse rate can be referred as

(a) super-adiabatic (b) sub-adiabatic
(c) neutral (d) inversion

Q.17 The following is a well known formula for estimating the plume rise:

$$\Delta h = \frac{V_s d}{u}\left(15 + 0.0096\frac{Q_h}{V_s d}\right)$$

where the letters have their usual meaning. The estimated plume rise (by the above formula) with a stack gas having heat emission rate 2000 kJ/s, the wind speed 4 m/s, stack gas speed 8 m/s inside a stack diameter of 1 m at the top is

(a) 7.8 m
(b) 8.7 m
(c) 3.15 m
(d) $\frac{8000}{\pi}(15 + 0.0024\pi)$

Q.18 In sampling of stack gases for measurement of concentration of Suspended Particulate Matter (SPM), the flue gases are sucked in the instrument at

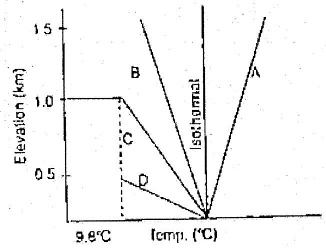
(a) any rate of flow from mid diameter of chimney
(b) any point of chimney cross-section and at any rate of flow
(c) a constant rate of flow but at four equidistant points along the diameter
(d) controlled positions and controlled velocities along the chimney diameter to get isokinetic conditions

Q.19 Which one of the following procedures is used for sampling of the flue gas in a chimney for SPM?

(a) Isothermal sampling
(b) Isokinetic sampling
(c) Adiabatic condition
(d) Variable rate of sampling

Q.20 The graph shows the relationship of ambient lapse rates to the dry adiabatic lapse rate under different conditions of stability. Match stability situations A, B, C and D (as given in the graph) with the classes of stability as follows:

1. Super adiabatic 2. Dry adiabatic
3. Sub adiabatic 4. Inversion



Select the correct answer using the codes given below:

	A	B	C	D
(a)	3	4	1	2
(b)	4	3	2	1
(c)	3	4	2	1
(d)	4	3	1	2

Q.21 Which type of light energy is effectively absorbed by CO_2 in the lower boundary of the troposphere?

(a) X-rays (b) UV-rays
(c) Visible light (d) Infrared rays

Q.22 Which one of the following pairs is not correctly matched?

Plume Behaviour		Atmospheric Condition
(a) Looping	:	Stable
(b) Fumigation	:	Inversion above and lapse below the stack
(c) Fanning	:	Inversion
(d) Trapping	:	Inversion above and below the stack with lapse in between

Q.23 Which one of the following pairs is not correctly matched?

(a) Coriolis effect : The effect of earth's rotation on wind direction and velocity
(b) PAN : Found during photochemical smog
(c) Cyclone : Employed for particulate matter removal
(d) Wind rose : Employed in forecast of pollutant dispersion in ambient air

Q.24 Match List-I (Air pollutant) with List-II (Impact on human health) and select the correct answer using the codes given below the lists:

List-I
A. Particulates
B. Carbon monoxide
C. Sulphur oxides
D. Photochemical oxidants

List-II
1. Impairs transport of O_2 in bloodstream
2. Irritation of mucous membranes of respiratory tract
3. Causes coughing, shortness of breath, headache, etc.
4. Causes respiratory illness

Codes:

	A	B	C	D
(a)	2	3	4	1
(b)	4	1	2	3
(c)	2	1	4	3
(d)	4	3	2	1

Q.25 Which type of plume may occur during winter nights?
(a) Looping (b) Inversion
(c) Coning (d) Lofting

Q.26 Pneumoconiosis is caused due to inhalation of which one of the following?
(a) Silica (b) NO_x
(c) Lead (d) Cadmium

Q.27 Which one of the following conditions of automobile gives maximum unburned hydrocarbons?
(a) Idling (b) Cruise
(c) Acceleration (d) Deceleration

Q.28 Electrostatic precipitator is most useful for which one of the following industries?
(a) Tannery
(b) Hydroelectric power generation
(c) Thermal power generation
(d) Textile factory

Q.29 Biological magnification of pesticides takes place through which of the following?
(a) Population pyramids
(b) Hydrologic cycle
(c) Food chains
(d) Air cycle

Q.30 Which one of the following toxic gases has physiological action as asphyxiant?
(a) SO_2 (b) NO_2
(c) Cl_2 (d) CO

Q.31 Assuming annual travel for each vehicle to be 20000 km, what is the quantity of NO_x produced from 50000 vehicles with emission rate of 2.0 g/km/vehicle?
(a) 1800 tonnes (b) 1900 tonnes
(c) 2000 tonnes (d) 2100 tonnes

Q.32 What are the air pollutants responsible for acid rain within and downwind areas of major industrial emissions?
(a) Hydrogen sulphide and oxides of nitrogen
(b) Sulphur dioxide and oxides of nitrogen
(c) Carbon dioxide and hydrogen sulfide
(d) Methane and hydrogen sulfide

Q.33 Consider the following air pollutants:
1. NO_x 2. PAN
3. CO_2 4. CO
Which of the above air pollutants is/are present in an auto exhaust gas?
(a) 1 only (b) 1 and 2
(c) 2 and 3 (d) 1, 3 and 4

Q.34 During temperature inversion in atmosphere, air pollutants tend to
(a) accumulate above inversion layer
(b) accumulate below inversion layer
(c) disperse laterally
(d) disperse vertically

Q.35 The mean indoor airborne Chloroform ($CHCl_3$) concentration in a room was determined to be 0.4 $\mu g/m^3$.
Use the following data: T = 293K, P = 1 atmosphere, R = 82.05×10^{-6} atm-m^3/mol-K.
Atomic weights: C = 12, H = 1, Cl = 35.5.
This concentration expressed in parts per billion (volume basis, ppbv) is equal to
(a) 1.00 ppbv (b) 0.20 ppbv
(c) 0.10 ppbv (d) 0.08 ppbv

Q.36 The dispersion of pollutants in atmosphere is maximum when
(a) environmental lapse rate is greater than adiabatic lapse rate
(b) environmental lapse rate is less than adiabatic lapse rate
(c) environmental lapse rate is equal to adiabatic lapse rate
(d) maximum mixing depth is equal to zero

Q.37 Total suspended particularte matter (TSP) concentration in ambient air is to be measured using a high volume sampler. The filter used for this purpose had an initial dry weight of 9.787 g. The filter was mounted in the sampler and the initial air flow rate through the filter was set at 1.5 m^3/min. Sampling continued for 24 hours. The airflow after 24 hours was measured to be 1.4 m^3/min. The dry weight of the filter paper after 24 hour sampling was 10.283 g. Assuming a linear decline in the air flow rate during sampling, what is the 24 hour average TSP concentration in the ambient air?
(a) 59.2 $\mu g/m^3$ (b) 118.6 $\mu g/m^3$
(c) 237.5 $\mu g/m^3$ (d) 574.4 $\mu g/m^3$

Q.38 Two primary air pollutants are
(a) sulphur oxide and ozone
(b) nitrogen oxide and peroxyacetylnitrate
(c) sulphur oxide and hydrocarbon
(d) ozone and peroxyacetylnitrate

Q.39 Match List-I with List-II and select the correct answer by using the codes given below the lists:

List-I	List-II
A. Coriolis effect	1. Rotation of earth
B. Fumigation	2. Lapse rate and vertical temp. profile
C. Ozone layer	3. Inversion
D. Max. mixing depth (mixing height)	4. Dobson

Codes:

	A	B	C	D
(a)	2	1	4	3
(b)	2	1	3	4
(c)	1	3	2	4
(d)	1	3	4	2

Q.40 An air parcel having 40° temperature moves from ground level to 500 m elevation in dry air following the "adiabatic lapse rate". The resulting temperature of air parcel at 500 m elevation will be
(a) 35°C (b) 38°C
(c) 41°C (d) 44°C

Directions: The following items consists of two statements; one labelled as **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) both A and R are true and R is the correct explanation of A
(b) both A and R are true but R is not a correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.41 **Assertion (A):** In recent years, there has been a progressive increase in the percentage of solar ultraviolet rays reaching the earth's surface.
Reason (R): In the last few years, there has been a progressive increase in the percentage of carbon dioxide in the earth's atmosphere.

Q.42 **Assertion (A):** The surface of sea water is on the rise.
Reason (R): A thick layer of gases enveloping the earth does not allow heat to pass into space from the earth at a rate which is as much as the rate at which the heat coming from space penetrates it towards the earth.

Q.43 **Assertion (A):** Traffic 'Smog' is likely to occur in regions where vehicle mileage is considerable and there is a low incidence of sunlight.
Reason (R): Traffic 'Smog' is caused by the reaction of oxides of nitrogen and some of the hydrocarbons in presence of bright sunlight.

Q.44 **Assertion (A):** Air pollutant concentration and time of retention increase due to inversion.

Reason (R): During winter, the heavy cold layer in the atmosphere retains the hot toxic pollutants for a longer period in the atmosphere.

Answers

1. (c)	2. (b)	3. (d)	4. (b)	5. (a)
6. (b)	7. (c)	8. (b)	9. (d)	10. (b)
11. (a)	12. (c)	13. (a)	14. (d)	15. (d)
16. (a)	17. (a)	18. (d)	19. (b)	20. (b)
21. (d)	22. (a)	23. (d)	24. (b)	25. (d)
26. (a)	27. (a)	28. (c)	29. (c)	30. (d)
31. (c)	32. (b)	33. (d)	34. (b)	35. (d)
36. (a)	37. (c)	38. (c)	39. (d)	40. (a)
41. (b)	42. (a)	43 (d)	44. (b)	

Hints and Explanations:

Ans.1 (c)

Carbon monoxide affect human aerobic metabolism by forming carboxyhaemoglobin (CoHb).

Oxides of nitrogen (NO_x) includes – nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), nitrogen sesquioxide (N_2O_3), Nitrogen tetroxide (N_2O_4) and nitrogen pentoxide (N_2O_5). NO and NO_2 are of primary concern as air pollutants. NO_2 plays major role in the production of secondary air pollutant ozone (O_3).

SO_2 is responsible for acid rains as it combines with water vapour to form secondary pollutants like H_2SO_4 which cause acidity.

Ans.3 (d)

Photochemically, the hydrocarbons and NO_x are the necessary ingredients to produce photochemical smog.

Unburnt Hydrocarbons

$$+NO_x \xrightarrow[\text{(Oxides of nitrogen)}]{\text{sunlight}} \text{smog}$$

The end product of these photochemical reactions is photochemical smog consisting of air contaminants such as O_3, PAN, aldehydes, ketones, alkyl nitrates and carbon monoxide.

Thus, oxides of nitrogen and unburnt hydrocarbons are responsible for causing photochemical smog.

Ans.4 (b)

(i) Electrostatic precipitator (High voltage) is used for > 1 mm but can collect submicron particles also.

(ii) Cyclone collector (based on centrifugal force) is used for 5 to 25 mm size particle

(iii) Wet scrubber are used for gaseous pollutants

(iv) Adsorbers are specific to gases. A reactive liquid adsorbent (water or limestone) may be used to remove SO_2 from flue gases.

Ans.6 (b)

Aerosols or particulates or suspended particulate matter is defined as the liquid or solid particles when they are suspended in gaseous medium. The term aerosol is used during the time it is suspended in air. After the particle is settled down, the term ceases to be valid.

Ans.8 (b)

$$\text{Quantity of air} = \frac{10^6}{50} \times 0.03 = 600 \text{ m}^3\text{/min}$$

Ans.10 (b)

Photochemical reactions form O_3, PAN, formaldehyde, etc.

Ans.12 (c)

Decomposer class includes saprophytic organisms that help in nutrients and element recycling process. These are bacteria, fungi and protozoans. They reduce organic matter to simple compounds and elements.

Ans.13 (a)

Soot is a general term that refers to impure carbon particles resulting from the incomplete combustion of hydrocarbons. Soot, as an air borne contaminant in the environment has many different sources but they are all the result of some form of pyrolysis.

Ans.14 (d)

Carbon dioxide is considered to be major greenhouse gas, as it is responsible for about 60% of the total greenhouse effect caused by all the greenhouse gases. Other green-house gases are CH_4, NO_x and chlorofluoro carbons.

Ans.16 (a)

Ambient lapse rate

$$= \frac{21.25 - 15.70}{(444 - 4)} \times 1000$$

$$= 12.6\ °\text{C/km} > 9.8°\text{C/km}$$

When the ambient lapse rate exceeds the adiabatic lapse rate, the ambient lapse rate is said to be super adiabatic.

Ans.17 (a)

Wind Speed u = 4 m/s

Stack gas speed V_s = 8 m/s

Diameter d = 1 m

Heat rise Q_h = 2000 kJ/s

We know that effective height of stack,

$$\Delta h = \frac{V_s \times d}{u}\left[1.5 + 0.0097 \times \frac{Q_h}{V_s \times d}\right]$$

$$\Delta h = \frac{8 \times 1}{4}\left[1.5 + 0.0097 \times \frac{2000}{8 \times 1}\right] = 7.8 \text{ m}$$

Ans.18 (d)

To obtain representative samples, selection of sampling site and the number of sampling point are the most important factors. The gas stream in the stack is normally under turbulent flow condition and any flow disturbance would result in non-uniform and unstable gas flow profiles and non-uniform particle concentration patterns. The other important factor in stack sampling is high temperature and high velocities of the gases encountered inside the stack. Therefore isokinetic technique is adopted for particulate laden gas stream. In this technique a sample is drawn into the probe such that the condition at the tip of the probe is same as those in the free gas stream at the sampling point. It can be carried out in two ways :

1. By computing point velocity of free stream by Pitot tube and adjusting sampling velocity.
2. By using a hull type of sampling probe, in which the static pressures measured between the inner and outer probe walls is balanced.

Ans.21 (d)

CO_2 is major greenhouse gas and absorbs long wave radiations like infrared radiation.

Ans.22 (a)

In looping, Environmental Lapse (ELR) is more than Adiabatic Lapse Rate (ALR) so atmosphere is unstable.

Ans.23 (d)

Wind rose diagram represents direction, frequency and velocity of the winds in a particular location. The direction of wind is characteristically from high pressure to low, but the Coriolis force tends to deflect air currents out of these expected patterns. Wind speed is measured by an anemometer, an instrument typically consisting of three or four hemispherical cups arranged on a vertical axis.

A pollution rose is used for plotting the data necessary to determine the source direction of specific air contaminants. The velocity of wind determines the travel time of a particulate to a receptor and also the dispersion rate of air contaminants.

Cyclone is a low pressure system in the northern hemisphere. Horizontal air movement is anticlockwise and the vertical movement is upward. Low pressure systems are usually associated with cloudy skies, gusty winds and atmospheric instability, and the formation of fronts. Under such unstable conditions dispersion of pollutants is likely, and air pollution problems are minimal.

Cyclone collectors are centrifugal collectors used for removal of 5–25 µm size particulate matter.

Ans.31 (c)

NO_x emitted by 50000 vehicles = 2.0 × 50000 = 100000 g/km

NO_x produced by 50000 vehicles for a distance of 20000 km

= 100000 × 20000 × 10^{-6} tonnes = 2000 tonnes

Ans.33 (d)

PAN (peroxyacetyl nitrate) is a secondary pollutant which is formed in the atmosphere by a photochemical reaction or by hydrolysis or oxidation. Alkenes like ethylene in the presence of sunlight react which nitrogen dioxide at high concentrations to form PAN and Ozone (O_3). This ethylene is produced in automobile exhausts and not PAN which is a secondary pollutant.

Ans.34 (b)

When the temperature of the environment increases with altitude, then the lapse rate becomes inverted or negative from its normal state. Negative lapse rate occurs under condition, usually referred to as inversion, a state in which the warmer air lies over the colder air below. The radiation inversion is a phenomenon occurring from the unequal cooling rates for the earth and air above the earth. Such an inversion in the environment helps in formation of fog when air is wet, and simultaneously catches gases and particulate matter, as it stops their upward lifting, thereby creating concentration of pollutants in our close environment.

Ans.35 (d)

The relation between µg/m³ and ppm is

$$1\,\mu g/m^3 = \frac{1\,ppm \times \text{molecular mass of pollutant in g/mol}}{\text{L/mol of pollutant at given temp. and pressure } (V_2)} \times 10^3\,L/m^3$$

By Avogadro's law, we know that

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

where P_1 = 1 atmosphere; T_1 = 0°C = 273 K

V_1 = volume at 0°C at 1 atmosphere = 22.4 L/mol

Given P_2 = 1 atmosphere; T_2 = 293 K

$$\therefore \quad V_2 = \frac{P_1V_1T_2}{P_2T_1}$$

$$V_2 = \frac{22.4 \times 293}{273}$$

V_2 = 24.04 L/mol

∵ 0.4 µg/m³ of $CHCl_3$

$$= \frac{CHCl_3 \text{ in ppm} \times 119.5 \times 10^3}{24.04}$$

⇒ $CHCl_3$ in ppm = 8.0469 × 10^{-5}

$CHCl_3$ in ppbv = 8.0469 × 10^{-5} × 10^3

= 0.08 ppbv

Ans.36 (a)

When the environment lapse rate is more than the adiabatic lapse rate, a rising parcel of warm lighter air (pollutants) will continue to lift up; whereas a parcel of heavier cooler air will continue to come down. In such circumstances, the environment is unstable and the dispersion of pollutants will be rapid due to marked vertical mixing of the air.

Ans.37 (c)

Average airflow rate

$$= \frac{1.5 + 1.4}{2} = 1.45\ m^3/min$$

Total airflow through the sampler during 24 hours

= 1.45 × 24 × 60 = 2088 m³

TSP concentration in the ambient air

$$= \left(\frac{10.283 - 9.787}{2088}\right) \times 10^6 = 237.5\ \mu g/m^3$$

Ans.38 (c)

Sulphur dioxide carbon monoxide, nitrogen oxides, lead, hydrocarbons, allergic agents like pollens and spores and radioactive substances are primary pollutants.

Sulphuric acid, ozone, formaldehydes and peroxyacylnitrates (PAN) are secondary pollutants.

Ans.40 (a)

Dry air cools at the rate of 9.8°C per km and it is called dry adiabatic lapse rate. In saturated (wet) air, this rate is calculated to be 6°C per km and is known as wet adiabatic lapse rate.

Resulting temperature of air

$$= 40 - 9.8 \times \frac{500}{1000}$$

$$= 40 - 4.9 = 35.1°C$$

Ans.41 (b)

Depletion of ozone layer (in stratosphere and mesosphere) has led to increased exposure of earth's surface to ultraviolet radiation. The ozone depleting substances are chlorofluoro carbons (CFCs).

Increased percentage of carbon dioxide has led to global warming (greenhouse effect).

Ans.42 (a)

Entrapping of infrared radiation emitted from earth's surface by greenhouse gases results in increase of temperature. This causes melting of polar ice caps and high mountains. The melted ice flows to oceans and the surface of sea water is on rise due to this.

Ans.44 (d)

The most common form of surface-based inversion is the *radiational inversion*. It occurs whereever, the surface of the earth can become cooler during the night and winters by the thermal radiation of energy. As a result of a decrease in temperature of the ground, the lower atmosphere in contact with it loses sensible heat through conduction, conversion, and more importantly, radiation. Consequently a temperature inversion, is setup between the cool low-level air and the warmer air above. This type of inversion is most pronounced during the late night and early morning hours and is sometimes called a *nocturnal inversion*. The effects of stable low-level air are evident early in the day when the smoke from chimney's and small fires is confined close to the ground.

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