day to day and may change even from hour to hour. All the elements of weather (temperature, pressure, wind, etc.) are not separate entities, rather they are closely related to each other.

On the other hand, climate describes a long period of time (about 30 to 35 years) and average weather conditions for a large area. Climate does not change from day to day or hour to hour.

4.11 AIR POLLUTION AND METEOROLOGY

The determining factor of air quality at a given site is weather, the wind speed, its direction, temperature profile, solar radiation, humidity, atmospheric pressure, etc. The study of the dynamics of atmosphere, which ultimately govern the air quality at a given site, is known as Meteorology.

Ambient Lapse Rate (ELR)

The rate of change in air temperature with altitude is called lapse rate. When a packet of air moves upward in the atmosphere, it experiences less pressure and hence it expands and cools down (expansion is done at the cost of internal energy of the air molecules and hence it cools down) and the surrounding air gains heat and becomes little hotter. On the other hand, when the packet moves down, more pressure will compress the air in the packet and its temperature will increase, consequently the surrounding air will be little cooler. This rate of change in air temperature with altitude or the lapse rate is known as **Ambient Lapse Rate or Prevailing Lapse Rate** and is also known as **Environmental Lapse Rate**. The Ambient Lapse Rate (ALR/PLR/ELR) differs from place to place, time to time even at the same place and depends on wind speed, geographical factors and sunlight. Experimentally, this can be measured by sending a balloon equipped with a thermometer and measuring temperature at different altitudes.

Adiabatic Lapse Rate

When a packet of air moves upward in the atmosphere, it experiences less pressure and hence, expands and cools down and the surrounding air gains heat and becomes little hotter. Now, if we assume that as the packet moves, there is no heat transferred across its boundary, the process is adiabatic. Under this condition, the lapse rate is called Adiabatic Lapse Rate (ALR).

The ease with which pollutants can disperse vertically into the atmosphere is largely determined by the rate of change in air temperature with altitude (Lapse rate). For some temperature profiles, the air is stable, *i.e.*, air remains stagnant at a given elevation and thus discourages dispersion and dilution of the pollutant. For some temperature profiles, the air is unstable and under such conditions there is rapid vertical mixing which encourages pollutant dispersal and increases air quality.

The relationship between atmospheric stability and temperature can easily be found out through a simple designed experiment. Let us imagine a packet of air with imaginary boundary that is moving up. This can be compared to a situation in which the air is enclosed in a cylinder and pressure is created by a piston or on the piston by the surrounding air.

Now assuming the air molecules to behave ideally, we can apply the first law of thermodynamics (the packet of air acting against the piston which is the surrounding air above it and heat is being drawn up from the surroundings while going up; the work is done by this packet of air).

$$dQ = dE + dW = dE + PdV$$

where,

dQ = heat added or drawn from the surrounding.

dE = change in the internal energy of the moving packet of air molecules.

dW = the work done by the packet of air to lift the surrounding air up.

P = constant atmospheric pressure against which the packet of air works.

dV = the change in the volume from initial to final.

Now we know, $dE = C_v dT$

where, C_v is the specific heat at constant volume, and dT is the change in the temperature of the air packet.

For ideal gas,

$$PV = RT \text{ (one mole of gas)}$$

or $$d(PV) = d(RT) = RdT$$

or $$PdV + VdP = RdT$$

or $$PdV = RdT - VdP$$

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Hence,

$$dQ = dE + PdV = C_v dT + PdV$$
$$= C_v dT + RdT - VdP$$
$$= (C_v + R)\, dT - VdP$$
$$= C_p dT - VdP$$

dP is the pressure change in the packet and C_p is the heat capacity at constant pressure.

Under adiabatic condition,

$$dQ = 0$$

Hence,

$$C_p dT - VdP = 0 \quad \text{or} \quad C_p dT = VdP$$

or $$\frac{dT}{dP} = \frac{V}{C_p}$$

The relationship shows how the atmospheric temperature would change with air pressure.

Now, we would like to find out how atmospheric temperature changes with the altitude.

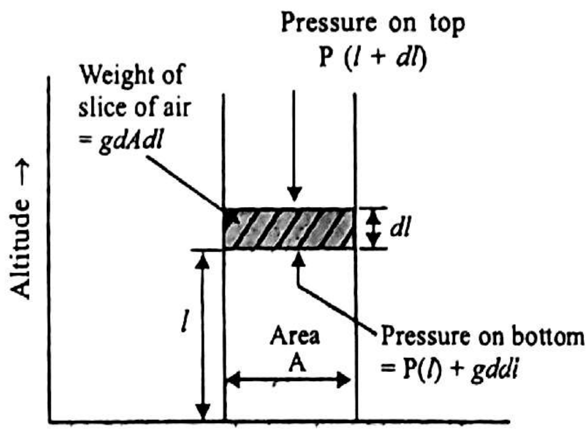

Fig. 4.8. Relationship between air pressure and altitude for a column of air in static equilibrium.

Consider a static column of air with cross-sectional area A. Now, a horizontal slice of air placed at a height of l cm from the base in a column with thickness ***dl*** and density ***d***, will have the mass ***dAdl***. For air to be static at a given height, internal pressure and external pressure must be equal. The internal pressure (pressure on the bottom of slice) is the atmospheric pressure $P\,(l + dl)$ plus the pressure of the slice $P\,(dl)$ due to its weight. Thus,

$$P\,(l) = P\,(l + dl) + P\,(dl)$$

Mass of the slice is $d.A.dl$

The pressure $P\,(dl)$ exerted by the slice of air,

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Dry Adiabatic Lapse Rate (DALR): When the packet of moving air is dry and the temperature is more than the dew point (the temperature at which dew is formed), the adiabatic lapse rate is called Dry Adiabatic Lapse Rate (DALR). The Dry Adiabatic Lapse Rate (DALR) is constant. DALR is constant at – 9.76°C/km.

Saturated Adiabatic Lapse Rate (SALR): When the packet of moving air contains a very small amount of moisture in it, then C_p change is negligible. On the other hand, if the air is saturated with moisture and temperature is less than the dew point, the adiabatic Lapse Rate is called Saturated Adiabatic Lapse Rate or Wet Adiabatic Lapse Rate (SALR). As the air is saturated with moisture, the movement which leads to cooling, condensation of water vapours occurs, releasing latent heat and the air packet will not cool as rapidly as happened with the dry one. Saturated adiabatic lapse rate is not constant since the amount of moisture that air can hold before condensation begins is a function of temperature. The average value of saturated adiabatic lapse rate in the troposphere is about – 5.4°C/km.

The packet of air moving into the atmosphere is neither absolutely dry nor fully saturated with moisture. The ALR therefore, lies between – 9.76°C/ km and – 5.4°C/km.

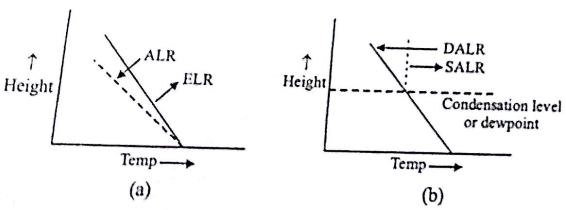

Fig. 4.9. (a) Graphical representation of ELR and ALR
(b) Graphical representation of DALR and SALR

4.11.1 Atmospheric Stability

Atmospheric stability is important because it determines the ability of pollutants to disperse vertically into the atmosphere and its ability to dilute pollution. Difference between the Ambient Lapse Rate and Adiabatic Lapse Rate determines the stability of the atmosphere.

There are three different cases of atmospheric stability:

(1) When ELR > ALR, then the atmosphere is unstable, *i.e.*, when the internal temperature of the air packet is higher than the surroundings, its density becomes lower and it keeps on going up.

(2) When ELR < ALR, then the atmosphere is stable, *i.e.*, internal temperature of air packet is lower than the surroundings, its density becomes higher and it goes down.

(3) When ELR = ALR, then the atmosphere is neutrally stable, *i.e.*, internal temperature of air packet is same as that of the surroundings, it experiences no forces that can make it continue its motion.

Sub-Adiabatic Lapse Rate/Sub-Adiabatic Condition of Atmosphere

When ELR < ALR, the atmosphere is said to be stable and this prevailing lapse rate is called sub-adiabatic lapse rate. Under sub adiabatic condition, dissipation of pollutant into the atmosphere will be slower than the unstable condition.

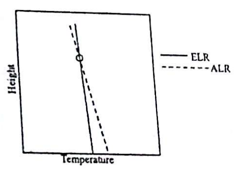

Fig. 4.10. Sub-adiabatic lapse rate.

Super Adiabatic Lapse Rate/
Super Adiabatic Condition of Atmosphere

When ELR > ALR, *i.e.*, the rate of cooling is faster than theoretical ALR, the condition of atmosphere under such circumstances is called super adiabatic condition of atmosphere. This condition is helpful in the dissipation of pollutants into the upper atmosphere and hence, eliminates air pollution problems.

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On a clean summer day, rapid heating of the earth by the sun warms the air near the surface and the lapse rate is super adiabatic. Under this condition, the atmosphere is under unstable equilibrium and results in vertical mixing of air. Under this condition, pollutants are rapidly dispersed.

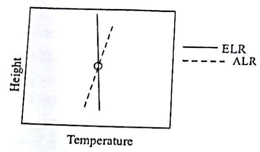

Fig. 4.11: Super adiabatic lapse rate

4.11.2 Temperature Inversion

Under normal situation, the temperature of air decreases with increasing altitude. In an unusual case, the temperature may increase with increasing altitude. This is known as temperature inversion. Under such condition, the lapse rate becomes inverted or negative from its normal state. This is called negative lapse rate. Temperature inversion represents the extreme cases of atmospheric stability, restraining upward movement of pollutants.

Three important causes of temperature inversion are:

(*i*) Radiation Inversion (*ii*) Subsidence Inversion (*iii*) Advective Inversion

(*i*) Radiation inversion: During the day, the sun heats the earth and air near it. At night, the ground and the air near it cool faster than that high up, creating an inversion. This is more prominent in winter. Radiation inversions generally start at dusk and with the progress of evening the inversion extends to a higher and higher elevation. At evening, the pollutants thus, get concentrated near the ground level. Without sunlight the photochemical reactions cannot occur and the biggest problem is the accumulation of carbon monoxide (CO). In the morning when the sun rises, inversion starts breaking up, although it may persist for few days in cold and cloudy weather and the pollutants that were trapped in the stable air mass are suddenly brought back to the earth through a process known as fumigation.

(*ii*) Subsidence inversion: Subsidence inversion is associated with anticyclones (high pressure weather system). This kind of inversion results when the upper layer of air descends (subsides) during a

developing anticyclone. The high pressure compresses the upper layer of air, thereby heating it. The lower layer of air on the other hand, is relatively colder and denser. This cold air cannot rise up due to the lack of any driving force and the atmosphere becomes stable. Thus, in this case of high level inversion, the lower inversion layer forms a lid for pollutants, causing them to accumulate and raise their concentration. Thus, if the subsidence inversion lasts for a long time, it will create a serious air pollution problem.

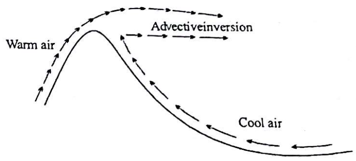

Fig. 4.12. Development of advective inversion

(*iii*) Advective inversion: This type of inversion occurs when warm air moves over cold air or a cold surface. Elevated advective inversion occurs when a hill range forces a warm land breeze to flow at high levels and a cool sea breeze flows at low levels in just the opposite direction.

4.11.3 Maximum Mixing Depth

The amount of air available to dilute pollutants depends on the wind speed as well as the extent to which the emissions can rise into the atmosphere. The emitted flue gas, being warmer and lighter than the surrounding air moves up. As it moves up, it may get cooled adiabatically at about 10°C/ km. The warmer flue gas will move up to the height where its temperature and density become equal to that of surrounding air. This height is known as maximum mixing height or maximum mixing depth.

The maximum mixing depth can be obtained simply by plotting ELR and ALR in a graph. The vertical distance from the point of intersection to the base is called the maximum mixing depth.

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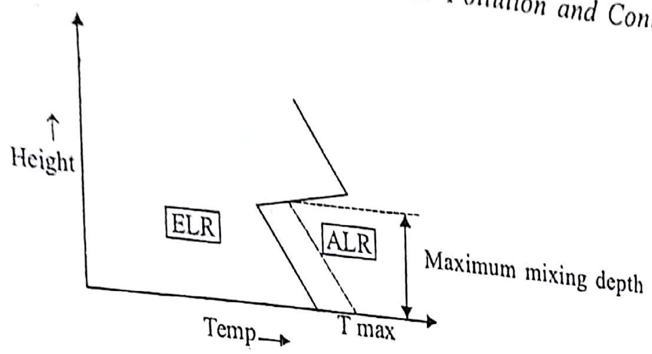

Fig. 4.13. Maximum mixing depth

4.11.4 Ventilation Coefficient

The product of the maximum mixing depth and the average wind speed in a region is called ventilation coefficient. Sometimes, this is used as an indicator of the atmosphere's dispersive capability. Ventilation coefficient less than 6000 m^2/s, is considered to be a bad condition for dispersion of pollutants.

The direction and speed of wind determines the drift and diffusion of polluted gases. The higher the wind speed at or near the point of emission, the greater will be the dispersion of pollutants from the source. If, however, the wind speed is low, the pollutants will concentrate near the area of their emission, indicating poor dispersion.

Wind speed and concentration of pollutants are thus, inversely proportional to each other. However, the simple relationship may get jeopardized by the humidity, geographical condition of a place and atmospheric stability and turbulence, etc.

4.11.5 Mixing Depth and Atmospheric Stability

We have seen that a packet or layer of air goes up when ELR > ALR (unstable atmosphere), goes down when ELR < ALR (stable atmosphere) and stays at the same position when ELR = ALR (neutral atmosphere).

The packet of air keeps on rising as long as it is warmer than the surrounding air and goes down when it becomes cooler than the surrounding air. Thus, just above a certain region there starts an oscillation that means that the air at a certain region experiences turbulent mixing. The altitude of the top of that mixed layer is called the mixing depth (or mixing height).

Fanning Plume

Under extreme inversion condition (due to negative lapse rate), fanning plume is obtained. Under condition of inversion, stable environmental condition exists just above the stack and plume does not move upwardly but horizontally.

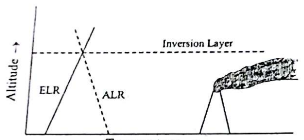

Fig. 4.15. Fanning plume

Looping Plume

Looping plume is of wavy character and occurs in super adiabatic environment (ELR>ALR), which produces highly unstable atmosphere because of rapid mixing.

In an unstable atmosphere, rapid air movements take place vertically, both upward and downward and the plume becomes a looping plume. As a result of this, high concentrations of pollutants may occur near the ground. To disperse these pollutants, it is advisable to design high stack where atmosphere is generally super adiabatic.

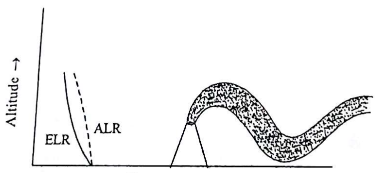

Fig. 4.16: Looping plume

Neutral Plume

Neutral plume occurs in neutral atmospheric conditions (ELR = ALR). Such type of plume rises vertically in an upward direction. The upward lifting of the plume will continue till it reaches a height where density and temperature of surrounding air are equal to it.

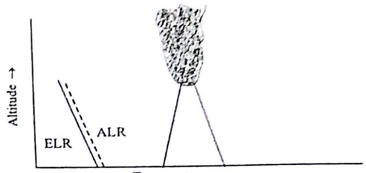

Fig. 4.17. Neutral plume

- **Lofting Plume**

Under conditions of strong super adiabatic lapse rate just above the stack and negative lapse rate (inversion) just below the opening of stack, lofting plume is obtained. The upward mixing of plume is very rapid and turbulent, but downward mixing is less because the downward movement is prevented by inversion.

The dispersion of pollutants therefore becomes rapid and pollutants cannot come down to the ground. Such kind of a plume is ideal for dispersion of air pollutants and protection of living beings to a great extent.

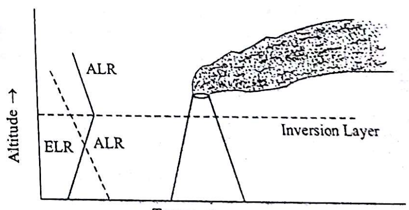

Fig. 4.18. Lofting plume

Fumigating Plume

Fumigating plume is just opposite to lofting plume. Under conditions of negative lapse rate (inversion) just above the stack and strong super adiabatic lapse rate below the stack, the type of plume obtained is known

as fumigating plum
not escape above
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as fumigating plume. Under these set of conditions, the pollutants can not escape above the stack, rather they come down near the ground due to turbulence and mixing. Fumigating plume, is therefore extremely bad for dispersion of pollutants.

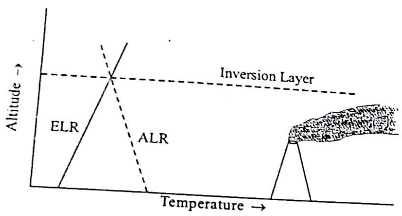

Fig. 4.19. Fumigating plume

Trapping Plume

When the inversion layer exists above the stack and as well as below the stack, the plume neither goes up nor goes down, rather, it gets confined or trapped between these two inversion layers. Such type of plume is therefore, termed as trapping plume. This plume is not ideal for dispersion of pollutants as it cannot go above a certain height.

It is however, to be noted that plume rise depends not only on the stability of atmosphere, but also on the buoyancy and momentum of exhaust gases. Momentum depends on mass and velocity of the gases leaving the stack and buoyancy on the molecular weight of the exhaust gases and its temperature compared to the ambient air.

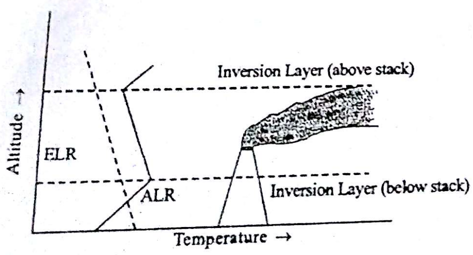

Fig. 4.20. Trapping plume

4.12.1 Effective Stack Height

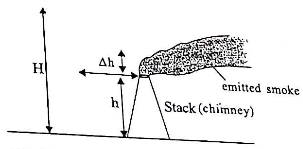

Fig. 4.21. Effective stack height for plume dispersion.

The effective stack height (H) is the height of the stack (h) plus the height (Δh) to which the plume rises above the stack.

Hence,

$$H = h + \Delta h$$

where, h = height of stack and Δh = plume height.

For stable atmospheric condition, the plume rise equation as suggested by Briggs in 1972 can be used. According to it

$$\Delta h = 2.6\left(\frac{F}{u_h S}\right)^{1/3}$$

where, S is the stability parameter, $S\ (s^{-2}) = \frac{g}{T_a}\left(\frac{\Delta T_a}{\Delta Z} + 0.01°\text{C /m}\right)$,

where, $\frac{\Delta T_a}{\Delta Z}$ is the rate of change of ambient temperature with altitude in °C/m.

F is the buoyancy flux parameter (m^4 / s^3) and is given by

$$F = gr^2 v_s\left(1 - \frac{T_a}{T_s}\right)$$

where,

Δh = plum rise

g = gravitational acceleration, 9.8 m/s^2.

v = inside radius of the stack

u_h = wind speed at the height of the stack, m/s

v_s = stack gas emit velocity, m/s

T_s = stack gas temperature, K

T_a = Ambient temperature, K

Plume rise depends on momentum and buoyancy. Buoyancy factor is due to the temperature difference of stack gases and surrounding air and the momentum due to the molecular weight of the exhaust gases against air.

For unstable atmospheric condition, the equation is somewhat complicated and is not discussed here.

In a simplified way the plume height or plume rise (Δh) is calculated using the following equation:

$$\Delta h = \frac{v_s x d}{u}[1.5 \times 2.7 \times 10^{-3} \times P.d(1-\frac{T_a}{T_s})]$$

where,

Δh = plume height

v_s = stack gas velocity

d = inside diameter of stack

u = atmospheric wind speed

P = atmospheric pressure

T_s = stack gas temperature

T_a = atmospheric air temperature

4.12.2 Effect of Wind Speed and Direction on Diffusion of Pollutants

With increase in wind speed the drift and diffusion of pollutants will be far away from the source of discharge and direction of wind will determine the direction of transport of the pollutants. Although, this is true in the plains, in case of terrain, the movement of pollutants is not fully dependent on the wind speed. The wind speed and direction on the other hand, are dependent on altitude and atmospheric conditions.

4.13 RESIDENTIAL AIR QUALITY

Most of our time is spent at home and severely exposed to chemicals and particulates. However, it is a tragedy that this has not received much attention.

The Source of Indoor Pollution

- Kerosene, gas stoves, smoking – carbon monoxide, particulate matter, sulphur dioxide (SO_2), NO_x gases.
- Furniture, carpet, cosmetics, paints, smoking, varnishes – volatile organic compounds.
- Tube light – Radon gas (a carcinogen).
- Fire proof, decoration, cement products – asbestos fibres.
- Hot shower, clothes, dish washing – chloroform.

The pesticides stored at home are bigger source of carcinogens. Various toxic chemicals, like Pb, Cd, Cr settled in the soil, are brought to homes through shoes. The traditional method of cooking using coal, wood and charcoal, without proper ventilation causes high degree of pollution and the women and the infant children are the main victims. Indoor pollution can be curtailed through common sense. Shoes should be kept outside the entrance of rooms, cooking should be done under proper ventilation by using exhaust fan. Paints and cleaning fluids should be well sealed.

4.14 COMMERCIAL AIR QUALITY

The commercial places are the business premises, shops and offices, market and departmental stores, godowns, etc. The building materials generate lot of hazardous pollutants, like asbestos fibers, particulate matter, radon, volatile organic compounds, formaldehyde, etc. At smaller establishments there is no proper ventilation system. People get affected by sick-building syndrome. Coughing, headache, dizziness, dry skin, fatigue are very common. The photocopying machines generate ozone, repairing of automobiles in commercial places, selling of new clothes, plastic bags, vegetable and fish remnants, fertilizers, pesticides, spoiled and discarded goods, all contribute to air pollution. Decomposition of organic waste and municipal garbage produces foul smelling gases, polluting the air.

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...erely exposed to chemicals
...hat this has not received

...oxide, particulate

...hes – volatile

4.15 INDUSTRIAL AIR QUALITY

There are big industrial estates, small and cottage industries that generate hazardous and toxic chemicals. The fertilizer plants, textile industry, glass industry, steel plants contribute SO_2, NO_x, smoke volatile organic compounds, chlorine gas, particulate matter, ammonia, CO, CO_2, phenol, cyanide to the atmosphere.

4.16 CONTROL OF PARTICULATE/FLUE GAS EMISSIONS

The most effective method of controlling air pollution is definitely to prevent the formation of air pollutants or to reduce their emission at the source itself. This can be achieved by using pure grade materials, modifying the process of formation, as well as the technologies. Even if all measures are taken, emissions of pollutants cannot be controlled fully and pollution controlled devices should, therefore be used. Some of the different devices for particulate emissions are:

(*i*) Baghouse
(*ii*) Cyclone separator
(*iii*) Scrubber
(*iv*) Catalytic converter
(*v*) Electrostatic precipitator

For controlling gaseous pollutants, the flue gases are flame combusted to have CO_2 and water vapour (almost full oxidation), for example, in a catalytic converter or if the flue gas contains enough SO_2, it is removed by its absorption or adsorption as in the scrubber.

(*i*) Baghouse: Such devices are used for collecting very small particles (~ 1 μm) through fabric filtration. A large chamber with several compartments containing fabric filter bags is called baghouse. The bags are distributed in the compartments so that when one compartment is under operation the other can be cleaned. Dust containing gases are passed through the bags and the dust particles are trapped (particle size ≥ 1 μm), after a certain time the particles adhered to the bags disallow particles of more smaller size (~0.01 μm). The efficiency of removal is as high as 100 per cent.

Baghouses, however, have many disadvantages:
(1) expensive (2) attacked by corrosive chemicals (3) cannot operate under moist conditions.

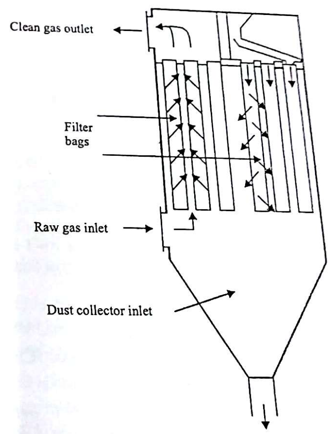

Fig. 4.22. Baghouse filter

(*ii*) Cyclone separator: For relatively large particles (5 – 20 μm), the control device used is cyclone separator. Gaseous emissions containing suspended particles enter tangentially near the top of the cyclone. As the gas spins, the centrifugal force causes dust particles to collide with the outer walls and then gravity causes them to fall down into the collector. The cleaned gas now escapes from the top. Whereas for particles larger than 5μm the efficiency of cyclone separator is about 90 per cent, for smaller particles it is less efficient. However, it is not expensive and is maintenance free.

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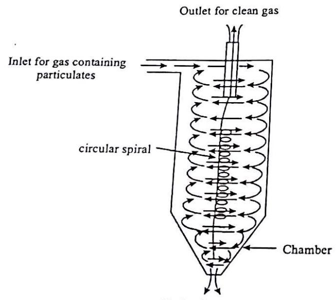

Fig. 4.23. Cyclone separator

***(iii)* Scrubber:** Scrubber is used for removal of SO_2 from flue gas. There are two methods:

(*a*) Wet method

(*b*) Dry method

(*a*) Wet method: In the wet method, pulverized limestone ($CaCO_3$) is mixed with water, slurry is made and sprayed into flue gases. Chemical reactions produce calcium sulphite ($CaSO_3 . 2H_2O$) and precipitate it out. The precipitate is removed as a sludge, which is later used in the construction industry.

$$CaCO_3 + SO_2 + 2H_2O \rightarrow CaSO_3 . 2H_2O + CO_2$$

It is a highly efficient (~ 90 per cent) method for removal of SO_2.

(*b*) Dry method: In this process, lime (CaO) is used for removal of SO_2.

$$CaO + SO_2 + 2H_2O \rightarrow CaSO_3 . 2H_2O$$

Although, the efficiency of removal in dry method is nearly 95 per cent, it is expensive due to the use of lime.

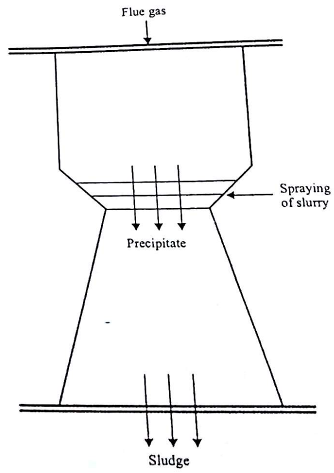

Fig. 4.24. Scrubber

(*iv*) Catalytic converter: Catalytic converter is used in the automobile engine for controlling emissions very effectively. Three-way catalytic converter is now available in the market. Three way means, removal of three pollutants such as CO, hydrocarbons and NO_x. In this type of catalytic converter, CO and hydrocarbon are oxidized to CO_2 and NO_x is reduced to N_2 in the same catalytic bed.

The catalytic converters not only control emissions but also allow engines to operate at near stoichiometric conditions. The efficiency of catalytic converter however, gets reduced drastically when leaded petrol is used.

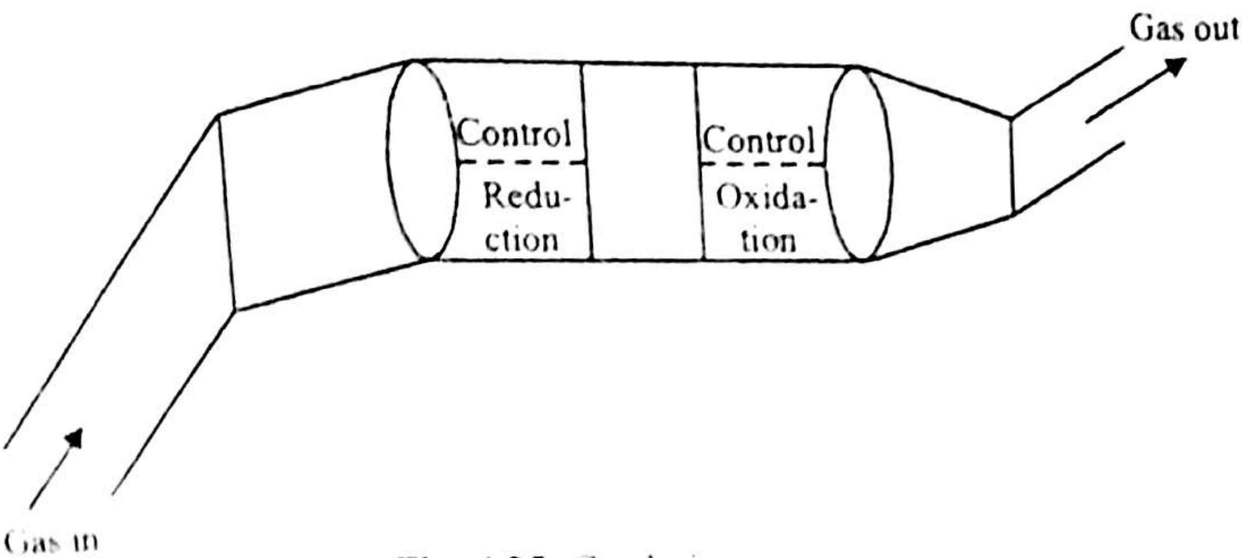

Fig. 4.25. Catalytic converter

(v) Electrostatic precipitator: This device is generally used in power plants for removal of very small particles (~1 µm). In this process, high voltage (100,000V) is applied to the wires connected to the grounded plates. The corona discharge in the wire ionizes the incoming gas, the positively charged gas molecules and electrons on their way to grounded plate adhere to the particulate matter. The particulate matter becomes charged and is attracted to the grounded surface, where they are removed either by flushing with liquid or by gravitational force.

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nuclear design coupled with mistakes by the plant operators, killing about 2000 people. It is estimated that almost all the xenon gas, half of iodine and caesium and about 5 per cent of the remaining radioactive material was released. Most of the material deposited in the nearby places as dust and debris, but the lighter material was carried by wind over Ukraine, Belarus, Russia and also to some parts of Scandinavia. The experts feel that agricultural fields in the nearby area will remain radioactive for decades to come and there remains the chance of spreading of cancer among people of the area.

QUESTIONS WITH ANSWERS

Q. 1. *(a)* What is atmosphere? What are the major regions of atmosphere?

(b) State the respective altitude and temperature ranges of the different regions. What are the important chemical species in each region?

Ans. *(a)* We live in a great ocean of air surrounding the earth called atmosphere. Atmosphere is a part of biosphere, the narrow sphere of earth where ecosystems operate. Atmosphere meets, interacts with other parts of biosphere namely hydrosphere (water) and lithosphere (soil) and makes the existence of life possible.

(b) The atmosphere is divided into five distinct layers characterized by the slope of its temperature profile. 1. Troposphere 2. Stratosphere 3. Mesosphere 4. Ionosphere/Thermosphere 5. Magnetosphere Exosphere.

1. Troposphere: This region extends from the earth (about 8-10 km at polar latitude, 12 km at moderate latitude and 18 km at the equator). The troposphere accounts for about 80 per cent of the atmospheric mass. The vertical temperature gradient of the troposphere is 5° per km in the lower and 7° per km in the upper region of troposphere. The upper region of troposphere is separated by the lower region of stratosphere in a narrow range called tropopause.

The uppermost region of troposphere in almost transparent to sun rays. The sun rays are mostly absorbed by the earth's surface due to various materials present in it. Some of the absorbed solar energy radiates as heat waves from the lower region of troposphere to the middle and finally to the upper troposphere. Thus, there occurs a gradual decrease in temperature with increase in height. Again, the non uniform

heating of the ground surface of earth due to uneven distribution of materials, ascending and descending air currents so produced results in turbulence and mixing of air mass. This mixing helps air to maintain good quality since it rapidly disperses pollutants. The temperature in the troposphere region varies from ground temperature to – 56°C with altitude. The average pressure at the earth's surface is 1,014 millibars—close to 1 atmosphere (atm). With increased height the air pressure decreases. Natural happenings like rains, storms, the thunder showers, etc., are found in this layer only. Because of climatic changes this layer has tremendous effect on the eco-system.

All living beings live in the troposphere. Although they are surrounded by air they can not see it, only feel it when it blows or when they breathe. Air has no colour, odour or definite shape, the volume percentage composition of clean air being – nitrogen 77.2 per cent, oxygen 20.6 per cent, carbon dioxide 0.04 per cent, water vapour varies from place to place, inert gases 0.94 per cent and other traces approximately 0.03 per cent.

2. Stratosphere: The layer above the tropopause is called stratosphere. Its thickness is about 50km above the earth surface and it consists of a rich layer of ozone. The short wavelength ultraviolet energy (190nm-380nm) is absorbed by ozone and oxygen, causing the air to be heated and simultaneously acts like a shield to protect life on earth from the harmful effect of this radiation. The temperature in this region continues to decrease with height and at 50 km attains a minimum of –2°C .

Stratosphere is therefore, a stable layer of very dry air with composition of ozone, oxygen and atomic oxygen. Pollutants that find their way into the stratosphere may remain there for many years before eventually drifting back to the troposphere and are finally removed by settling or precipitation.

The upper region of stratosphere is separated from the lower region of mesosphere by a narrow range called stratopause.

3. Mesosphere: This is the region above stratosphere and extends up to a height of 85 km above the earth surface. Concentration of ozone is very low in this region and decreases rapidly with increase in height. Thus, there is a decrease in absorption of solar radiation and temperature falls to – 92°C. The dominant chemical species found in this region are O_2 and NO. It has the highest clouds which often seem visible in clear weather. Meteors and upward convection air current cause these clouds. This layer is also responsible for reflecting all sound waves moving upwards from the earth. Beyond this layer lies the valley of silence.

The upper region of mesosphere is separated from the lower region of thermosphere by a narrow range called mesopause.

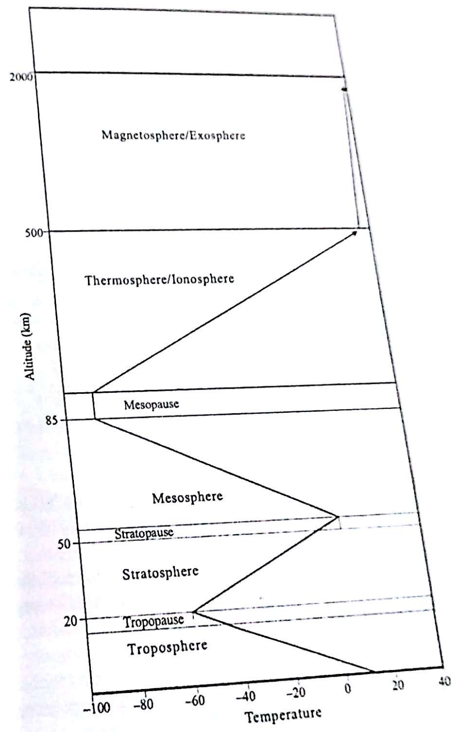
4. Thermosphere/Ionosphere: This is the region immediately above the mesopause, where temperature rises very rapidly with increasing altitude. It extends up to 500 km above the earth surface. The most dominant chemical species in this region are O_2, NO and atomic oxygen (O). They absorb x-rays and γ-rays. The maximum temperature in this region is about 1200°C. The heating of the thermosphere is due to absorption of solar energy by atomic oxygen (O). Within the thermosphere is a relatively dense band of charged particles (O_2^+, NO^+, O^+ and electrons) called the ionosphere. The ionosphere is highly electrically conducting as it contains charged particles produced from hydrogen, oxygen, helium, ozone, etc.

Before the introduction of satellites, the ionosphere was important for world wide communication due to its ability to reflect short radio waves back to earth.

5. Magnetosphere/Exosphere: Very little is known about this layer. It exists above ionosphere and extends approximately up to 2000 km above the earth. This layer is almost airless and empty. It probably contains hydrogen gas in ionized state. It has very high temperature and merges to airless, dark, black interplanetary space.

Table 4.2. Characteristics of the various regions of the atmosphere

Region	*Height above the earth's surface*	*Temperature(°C)*	*Major chemical species*
Troposphere			
Polar latitude	0 – 10		
Moderate latitude	0 – 12	15 to –56	N_2, O_2, CO_2, H_2O(vapour)
Equator	0 – 18		
Stratosphere			
Polar latitude	10 – 50		
Moderate latitude	12 – 50	– 56 to – 2	O_3, O_2, O
Equator	18 – 50		
Mesosphere	50 – 85	– 2 to – 92	O_2, NO
Thermosphere/ Ionosphere	85 – 500	– 92 to 1200	O_2^+, NO^+, O^+
Magnetosphere/ Exosphere	500 – 2000	≈1200	H_2^+



Temperature profile curve of the atmosphere

Q. 2. What is an air pollutant? Classify air pollutants. What do you mean by criteria pollutants?

Ans. A toxic substance, living or non living, at an undesirable limit is called a pollutant. Such a substance when present in air is called air pollutant. The process of making air polluted and making it unsafe for living beings is called pollution of air.

An alteration of the composition of the atmosphere by the introduction of potentially harmful substances will cause pollution and affect life on the earth severely.

The pollutants thus, emitted can be classified into two groups, namely (1) Primary pollutant (2) Secondary pollutant.

Primary pollutants: In this case, the substances are emitted directly into the atmosphere. For example, nitrogen oxides, carbon oxides and surface oxides which are produced when fuels are burnt.

Fuels (H, C, N, S, Pb, ash) + air $(N_2 + O_2) \rightarrow$

Emissions $\left(CO_2, H_2O, CO, N_xO_y, SO_x, Pb, PbO, \text{particulates}\right)$ + ash

Secondary pollutants: In this case, the substances are not emitted directly into the atmosphere but are formed by various physical processes in the atmosphere. For example, ozone which is formed through some chemical process, *i.e.*, not obtained directly but through secondary reactions. The other example cited are formaldehyde, acrolein, peroxyacyl nitrate (PAN).

Criteria Pollutants

There are six pollutants which have the main contribution in creating air pollution. They are primary pollutants like carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), lead (Pb) and particulate matters (PM) and secondary pollutants like ground level ozone (O_3).

There are other pollutants which are although, not criteria pollutants, but are dangerous and as well as toxic. They are volatile organic compounds and toxic chemicals.

Q. 3. (*a*) What is global warming?

(*b*) Which gases are responsible for global warming?

(*c*) How do greenhouse gases cause warming?

(*d*) What is greenhouse effect? Why is it named so?

Ans. (*a*) The gradual increase in earth's temperature due to emission of excessive amount of radiation trapping gases is called 'global

warming'. Although, the rise in temperature occurs at a slow rate, if proper measures are not taken, our survival will be threatened.

(*b*) The gases responsible for global warming are (*i*) Water vapour (*ii*) Carbon dioxide (*iii*) Methane (*iv*) Nitrous oxide (*v*) Ozone (*vi*) Halocarbons.

(*c*) The greenhouse gases act as a thermal blanket, absorb the radiation, heat the atmosphere and radiate some energy back to earth and little energy to the space. In this way, earth's average temperature is maintained. But due to rapid industrialisation excessive amount of greenhouse gases are emitted to the atmosphere, causing imbalance and consequently gradual rise in temperature.

(*d*) The greenhouse gases absorb the infrared light (heat energy) and re-emit some of the energy to the earth surface again to maintain surface temperature of the earth in the optimum level. This phenomenon is known as 'greenhouse effect'.

The term greenhouse effect is based on the concept of a conventional greenhouse where the glass enclosing the green plants is acting as blanket.

Q. 4. What is the consequence of global warming on the global climate? Discuss with reference to sea water level, agriculture and marine food. In what way 'global warming' can be controlled?

Ans. Effect on climate: Increase in average global temperature, due to global warming, will lead to rapid evaporation of water from various resources. The result will lead to increase in rainfall. The rainfall may not be even in all parts of the world, thus, there might be heavy rainfall in one part and drought in the other part. In consequence, we may have prolonged hot summer and shorter and warmer winter.

Effect on sea water level: Increase in temperature will lead to melting of ice caps and glaciers. All this will lead to an increase in liquid water. Again, with rise in temperature there will be volume expansion of water which will lead to rise in sea water level. When this would happen, the low land area will be flooded and even some countries lying in the low-land area will be wiped out.

Effect on agriculture: Increase in temperature leads to increase in rainfall but not evenly in all the parts. In the area which is under drought, plants will not grow due to scarcity of water and high temperature. In the part which receives highest rainfall, the chances of soil erosion become prominent and washing away of the fertile top soil hampers the

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plant growth. As a consequence, crop production is adversely affected. Although, at first glance it seems that heavy amount of CO_2 will lead to enhanced photosynthesis rate, but what more is required for photosynthesis is water and soil nutrient. Scarcity of these elements will not help photosynthesis.

Effect on marine food: An increase in temperature leads to volume expansion. As a result, the pH and concentration of salt in sea water changes (pH increases and salt concentration decreases). The increase in average temperature and changes of other factors become unsuitable for the different marine living organisms. Again, the marine algae, which are the autotrophs of marine living organisms, will also die due to the adverse condition.

Control of global warming

As greenhouse gases are the main components of global warming a fruitful thought must be given on this issue. One will have to emphasize on reducing the sources of production of such gases. Thus, the following steps might be observed to control 'global warming':

(*i*) Consumption of fossil fuels such as coal and petroleum should be reduced and non-conventional renewable sources such as solar energy, wind and biogas should be emphasized.

(*ii*) Enough plantations should be done so that excess CO_2 is consumed.

(*iii*) The greenhouse gases should be utilised to form some stable and useful products by inducting proper technology.

(*iv*) Vehicles with small carrying capacity should be substituted by vehicles having high carrying capacity.

(*v*) International cooperation is needed for controlling greenhouse gases.

Q. 5. (*a*) Define Lapse rate.

(*b*) What is atmospheric stability? Discuss with its importance.

(*c*) Why tropospheric lapse rate is reversed to that of stratospheric lapse rate?

Ans. (*a*) The rate of change of air temperature with altitude is called lapse rate. Lapse rate can be (*i*) Ambient lapse rate (*ii*) Adiabatic lapse rate.

(*b*) Atmospheric stability is the condition in which it will be able to disperse or dilute the pollutants.

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(*b*) The incoming solar energy just outside the earth's atmosphere has wavelength less than 3 μm (λ_{max} = 0.5 μm), while the outgoing energy radiated by the earth has essentially wavelength greater than 3 μm (λ_{max} = 10.1 μm).

In the attempt to pass through the atmosphere, the energy is affected by various atmospheric gases as well as by aerosols. It is known that a molecule absorbs energy only when the frequency of its oscillation matches with the frequency of radiation. Thus, most of the long wavelength energy radiated by the earth is absorbed by gases like H_2O (water vapour), CO_2, CH_4, N_2O and O_3 (greenhouse gases). However, radiant energy having wavelength between 7 to 12 μm is not absorbed by any atmospheric gases due to frequency mismatch. As a result, the radiated energy (40 W/m^2) in the frequency range of 7 to 12 μm easily escapes into the space. This relatively clear sky for this outgoing energy is referred to as the 'atmospheric radiative window.'

If there had been no atmospheric window, all energy would be trapped and the earth's temperature would be different making life uncomfortable and in extreme cases life would not exist.

(*c*) In stratosphere the concentration of ozone is the maximum hence, it is also called ozonosphere.

The formation of ozone involves the following steps:

The oxygen molecule in the stratosphere is dissociated by UV rays to atomic oxygen. The atomic oxygen then combines with the other associated oxygen molecules to produce ozone.

$$O_2 \xrightarrow{h\nu} O + O \quad \text{...(1)}$$

$$O + O_2 \rightarrow O_3 \quad \text{...(2)}$$

The ozone molecule thus formed, is dissociated again by the UV rays to produce molecular oxygen and atomic oxygen which again recombine immediately to reform ozone and the process continues.

$$O_3 \xrightarrow{h\nu} O_2 + O \quad \text{...(3)}$$

$$O_2 + O \rightarrow O_3 \quad \text{... (4)}$$

Ozone may be destroyed to form molecular oxygen.

$$O_3 + O \rightarrow O_2 + O_2 \quad \text{...(5)}$$

The sequence of steps (1) to (5) followed in the formation and balancing of ozone is called Chapman Reaction. With increased height, the ozone layer is more exposed to high energy ultraviolet radiation and the concentration decreases. The overall effect is the formation of balanced amount of ozone in the stratosphere. The layer of ozone thus, formed is also known as Chapman layer.

The role of ozone is manifold. It acts as a policeman in stratosphere and guards us from the hazardous UV radiation. Prevention of UV radiation protects us from many diseases, noteworthy being skin cancer. It also helps to maintain earth's heat budget.

Q. 7 (*a*) What are the differences between photochemical smog and sulphurous smog?

(*b*) What are the adverse effects of ozone hole formation?

Ans. (*a*) The main differences between photochemical smog and sulphurous smog are presented in a tabular form as follows:

Photochemical smog	*Sulphurous smog*
1. First time observed at Los Angeles, USA.	1. First time observed at London, U.K.
2. Main components are hydrocarbons, N_xO_y (various oxides of nitrogen) and ozone.	2. Main components are SO_x (SO_2 and SO_3, etc.)
3. Proceeds through free radical mechanism.	3. May not proceed through free radical mechanism.
4. This is oxidising type of smog.	4. This is reducing type of smog.
5. PAN is the main byproduct of this smog.	5. Sulphur salts are the main by-products of this smog.
6. Subsidence inversion is suitable for this type of smog.	6. Radiation inversion is suitable for this type of smog.
7. Temperature of this smog is greater than 25°C.	7. Temperature of this smog is less than 5°C.
8. Midday summer is the ideal condition for its formation.	8. Early morning of winter is ideal for its formation.
9. Most adverse effect is eye irritation.	9. Most adverse effects are lungs and throat irritation.

(*b*) Due to ozone hole, hazardous ultraviolet rays pass through and reach the earth's atmosphere. As is known, UV is responsible for skin cancer and aids other diseases to grow by disturbing the immune system of the living body. It may also destroy the ecological balance.

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