UNIT – I

AIR POLLUTION

Objective: To learn the concept of air pollution, types, sources and effects.

Syllabus: Air pollution- Definitions, Scope, Significance and Episodes, Air Pollutants; classifications-Natural and Artificial, Primary and Secondary, point and non-point, Line and Areal sources of air pollution- stationary and mobile sources, Ambient air quality by WHO (World Health Organisation) & CPCB (Centra Pollution Control Board)

Learning Outcomes: To evaluate the ambient air quality based on the analysis of air pollutants.

Definition of terms related to air pollution and control:

Air pollution: - concentration of foreign matter in air in excessive quantity which is harmful to the health of man.

Indoor air pollution: - Pollution from the housing materials and living and working activities of the house, such as: natural radiation-radon, domestic combustion-coal gas, and human habits tobacco smoking.

Outdoor air pollution: - Pollutions from outdoor services and environmental mixings, such as: transportation-automobiles, industries-refineries, atomic energy plant-nuclear, and community activities-cleaning of streets

Acute effects: - with in twenty four hours of sudden exposure to polluted air illness would occur.

Delayed effect: - The cause and effect relationship of air pollution and chronic effects on health is in a way difficult to prove due to long time contact and accumulation effect.

Aerosols: - Small solid or liquid particles (fine drops or droplets) that are suspended in air.

Dust: - aerosols consist of particles in the solid phase.

Smoke: - aerosols consist of particles in the solid- and sometimes also liquid-phase and the associated gases that result from combustion.

Ash: - aerosols of the solid phase of smoke, particularly after it settles into a fine dust.
Particulates: - Small particles, that travel in air and settles or lands on something.

Fumes: - are poly dispersed fine aerosols consisting of solid particles that often aggregate together, so that many little particulates may form one big particle.

Inhalable fraction: - Particles less than 100 μm that can be inhaled into the respiratory tracht (trachea).

Thoracic fraction: - Those particles below 20 μm, that can penetrate into the lungs.

Respirable range: - the greatest penetration and retention of particles is in the range 10.0 to 0.1 μm.

Mist: - A cloud or dense collection of droplets suspended in air.

Vapour: - The evaporated compound in the gas phase.

Troposphere: - The first and lowest of the atmospheric layers is called the "troposphere".
Stratosphere: - The second layer of air is called the "stratosphere"

Ionosphere: - Above the stratosphere is the "ionosphere" the top of which is the border line space.

Thermosphere:- This is a region of highly ionized gases, extending to about 1600 km.
Mesosphere: - Above the stratosphere, or the middle layer.

Wind: - Is simply air in motion

Scope:

Air pollution is a major environment-related health risk to children and a could cause both acute and chronic respiratory disease. Air pollution is an indirect threat to the food production. Crops can be injured when exposed to high concentration. To prevent this problem, we need to increase awareness among students about the air pollutants and their effects on the environment and how to control the pollution by using different types of equipments. Presently we are in 21st Century, the main problem these days is pollution of air. Exponential increase in automobiles and industries abnormally increase the pollution of air. To provide a better future for our next generation it is necessary to take some measures to preserve our environment.

Significance:

Man can survive for 5 weeks without food, 5 days without water and less than 5 minutes without air. Man can breathe on an average 25000 times a day. Compared to the consumption of water of about 2 liters a day (2kg/day) man can consumes about 20,000 more of air by volume and 25 times more by weight. In addition, the air he breathes goes into direct contact with the most sensitive organs of the human body-the respiratory tract and lungs. Thus the quality of air he breathes has a direct bearing on his health and well being. A concentration of more than 0.3 ppm i.e, 0.3mg/l or 3,00,000 μg/m^3, of lead in water is considered harmful to man but a concentration of 1.5 μg/m^3 of lead in air is deadly harmful. Majority of air pollutants have direct effect on man, vegetation and material. The air pollutants can affect the environment on a global scale. Carbon monoxide as a green house gas causes global warming, increases mean sea level, submerges millions of hectares of fertile land and brings famine, thus leading eventually to destruction of life. Sulphur dioxide can bring acid rains which can completely upset the delicate the balance between the various biotic and abiotic components of the biosphere. CFCs, the chloroflurocarbons can destroy the ozone layer, mans protecting umbrella and spread incurable diseases among human beings and other animals.

Episodes:

1. The great smog of 1952

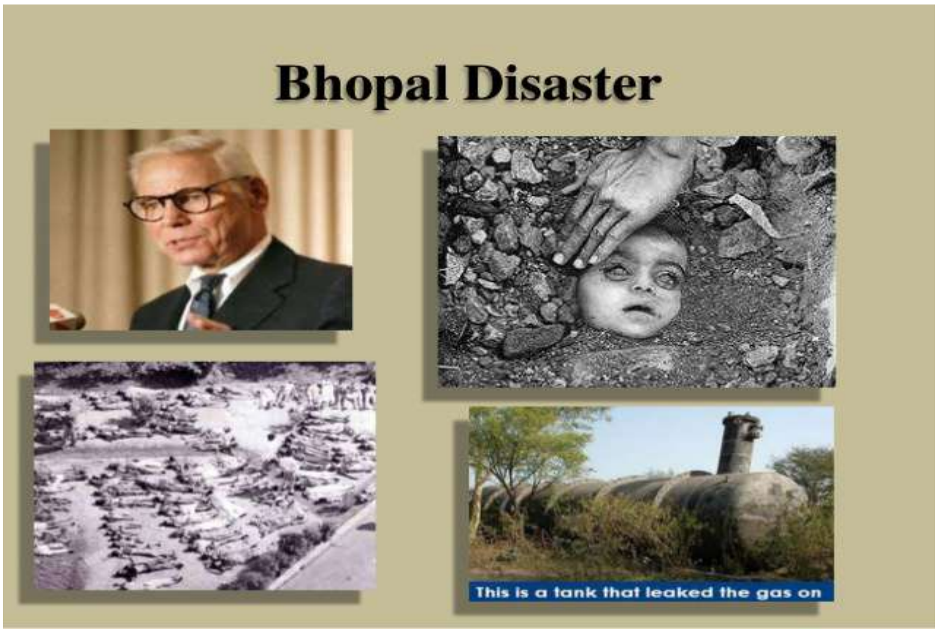
- December 5-9,1952 Great London Smog
- Heavy smog (smoke + fog) conditions due to high sulphur dioxide (1.3 parts per million) content prevailed in London
- 5 days of worst smog city had ever seen.
- Killed about 4,000 people in one week.
- Public transportation stopped
- Indoor concerts had to be cancelled because no one could see the stage, etc.
- Weekly death registered from diseases of the lungs and heart in the London Administrative County around the time of the severe fog in December, 1952

2. Bhopal gas incident in 1984

- Bhopal, India Dec. 3, 1984
- Union Carbide pesticide plant leak kills up to 2,000 with up to 350,000 injured and 100,000 with permanent disabilities
- Methyl isocyanate (MIC)—used as an intermediary in manufacture of Sevin (Carbaryl)
- CO + Cl = phosgene
- Phosgene + methylamine = MIC
- MIC—irritant to the lungs---edema, fluid (cause of death, bronchospasms, corneal opacity

Reason:

- A leak of methyl isocynate (MIC) gas and other chemicals from the plant
- Water entered a tank consists of 42 tons of MIC.
- The resulting exothermic reaction increased inside the tank to over 200^0C and raised the temperature.
- The gases were blown by northwesterly winds over Bhopal.



Year and Month	Location	Excess deaths reported
1873,Dec. 9-11	London, England	250
1880,Jan. 26-29	London, England	1000
1892,Dec.28-30	London, England	
1930,December	Meuse Valley, Belgium	63
1948,October	Donora, Pennsylvania	20
1948, Nov.26- Dec.1	London, England	800
1950, November	New York, New York	250
1956, Jan. 3-6	London, England	1000
1957, Dec. 2-5	London, England	800
1958	New York, New York	
1959, Jan.26-31	London, England	250
1962, Dec.5-10	London, England	700
1963, Jan.7-22	London, England	700
1963, Jan.-Feb.12	New York, New York	400
1966,Nov.23-25	New York, New York	170
1976, July	Sevesco. Italy	
1984, December 2	Bhopal, India	2500
1986, April	Chernobyl, Ukraine	2500

Air Pollutants:

What is air pollution?

Air pollution can be defined as the presence of toxic chemicals or compounds (including those of biological origin) in the air, at levels that pose a health risk. In an even broader sense, air pollution means the presence of chemicals or compounds in the air which are usually not present and which lower the quality of the air or cause detrimental changes to the quality of life (such as the damaging of the ozone layer or causing global warming).

What are the causes of air pollution?

Air pollution is probably one of the most serious environmental problems confronting our civilization today. Most often, it is caused by human activities such as mining, construction, transportation, industrial work, agriculture, smelting, etc. However, natural processes such as volcanic eruptions and wildfires may also pollute the air, but their occurrence is rare and they usually have a local effect, unlike human activities that are ubiquitous causes of air pollution and contribute to the global pollution of the air every single day.

Sources

Outdoor pollutants

– Natural – volcanic eruptions, forest fires, dust storms, etc.

– Human pollutants:

• Stationary sources (power plants & factories)

• Mobile sources (vehicles)

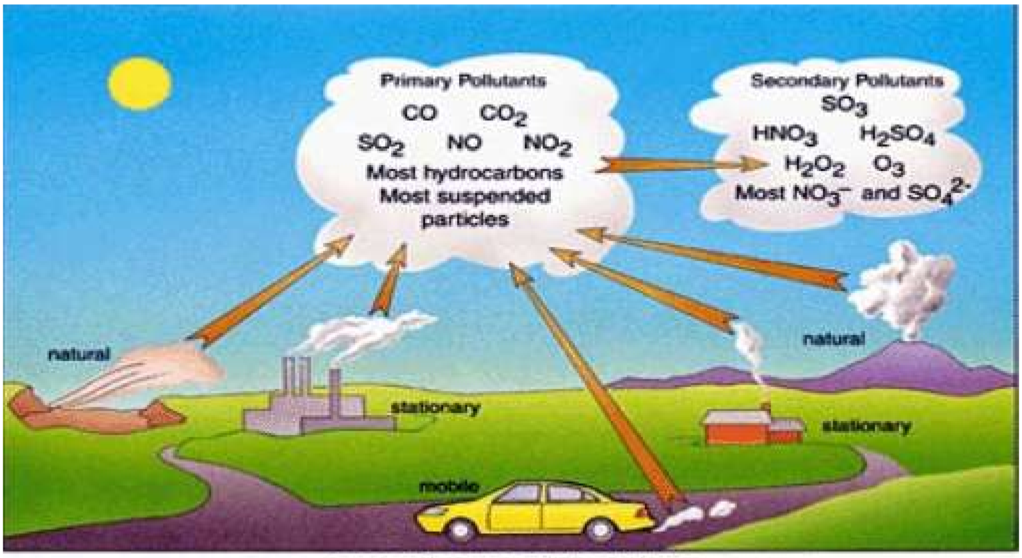
What is air pollutant?

Any substance in air that could, in high enough concentration, harm animals, humans, vegetation, and/or materials. Such pollutants may be present as solid particles, liquid droplets, or gases.

Classification of air pollutants:

Air pollutants and their sources may be classified as follows,

- Primary and secondary pollutants
- Natural and Artificial



Types and sources of air pollutants

Primary air pollutants - Materials that when released pose health risks in their unmodified forms or those emitted directly from identifiable sources.

Five major gases released directly into the atmosphere in unmodified forms.
-Carbon monoxide
-Sulphur dioxide
-Nitrogen oxides
-Hydrocarbons
-Particulate matter

Carbon Monoxide:

- Produced by burning of organic material (coal, gas, wood, trash, etc.)
- Automobiles biggest source (80%)
- Cigarette smoke another major source
- Toxic because binds to **Haemoglobin** , reduces oxygen in blood
- It combines with oxygen to form CO2
- Rush hour traffic can produce high CO levels

Sulphur Dioxide:

- Colourless gas with a pungent odour.
- It is produced from the combustion of any sulphur-bearing material.
- Sulphur dioxide, SO_2 is always associated with a little of sulphur trioxide, SO_3.
- $S + O_2 > SO_2$
- $2SO_2 + O_2 > 2SO_3$

Man-made sources—coal-fired power stations and other industries contribute about 33 per cent of SO_x pollution while natural sources, viz. volcanoes provide about 67 per cent of SO_x pollution.

Nitrogen Oxides:

- Consists of mixed oxides, nitric oxide and nitrogen dioxide (NO and NO_2)— the former is a colourless and odourless gas but the later (NO_2) has a reddish brown colour and pungent smell
- Produced from burning of fossil fuels
- Contributes to acid rain, smog

- Automobile engine main source

Hydrocarbons:

- Hydrocarbons - organic compounds with hydrogen, carbon
- Natural processes, particularly trees emit large quantities of hydrocarbons in air.
- Incomplete burning or evaporated from fuel supplies.
- Major source is automobiles
- Contribute to smog
- Methane, CH_4 is a major hydrocarbon. It is generated in large quantities by bacteria formed by anaerobic decomposition of organic matter in water sediments and soil.

Particulates:

- Particulates - small pieces of solid materials and liquid droplets (2.5 mm and 10 mm)
- Examples: ash from fires, dust
- Some particulates are known carcinogens

Secondary air pollutants - Primary pollutants interact with one another, sunlight, or natural gases to produce new, harmful compounds.

Examples: Ozone, Formaldehyde, PAN, Smog, photochemical smog.

Photochemical smog:

Photochemical smog is a mixture of air pollutants formed by the reaction of nitrogen oxides and volatile organic hydrocarbons when they are exposed to sunlight.

The oxygen atom reacts with other components of automobile exhaust (e.g. unburnt hydrocarbons) and those of the atmosphere (e.g. oxygen) in a series of complex reactions to produce a variety of lachrymatory and toxic chemicals (e.g. peroxyacetyl nitrate).
The production and destruction of photochemical smog are very complex events that involve hundreds of different chemical reactions.

In the first step of photochemical smog production, sunlight acts on nitrogen dioxide to produce nitric oxide and free oxygen:

$$NO_2 + h\upsilon \rightarrow NO + O$$

Oxygen atoms formed in this reaction react readily with diatomic oxygen present in the atmosphere to form ozone (O_3). The symbol *M* in the following equation represents some third body that acts as a catalyst, removing energy from the O_2/O collision, making it thermodynamically feasible:

$$O + O_2 + M \rightarrow O_3 + M$$

Levels of ozone produced by this reaction are controlled to some extent by a “scavenging” reaction that takes place with nitric oxide:

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

The reaction is referred to by this term because nitric oxide forages among ozone molecules, attacking them at random and converting them to oxygen molecules.

These three reactions constitute a cycle that begins with the production of nitrogen dioxide (usually from motor vehicle exhaust) and results in the production of large amounts of atomic oxygen and ozone.
When concentrations of nitrogen dioxide decrease (as during evening hours, when traffic tends to decrease), the scavenging reaction tends to remove excess amounts of ozone from the atmosphere.

Effects of photo chemical smog:

1. The compounds of formaldehyde, acrolein and PAN are highly irritant to eyes.
2. Vegetation is badly affected by the photo chemical smog.
3. Carbon, sulphur and halides present in the smog cause visibility problems.
4. Ozone present in the photo chemical smog badly damages the side walls of automobile tyres unless anti-ozonants are used.

The photo chemical smog can only be controlled by controlling the pollutants responsible for its formation.

Ozone:

- Ozone (O3) is a highly reactive gas composed of three oxygen atoms.
- It is both a natural and a man-made product that occurs in the Earth's upper atmosphere (the stratosphere) and lower atmosphere (the troposphere).

PAN:

- Formed by the interaction of some hydrocarbons and oxidants under the influence of sunlight peroxy acetyl nitrate.

Aerosols and mists (H2SO4):

Aerosols and mists are very fine liquid droplets that cannot be effectively removed using traditional packed scrubbers.

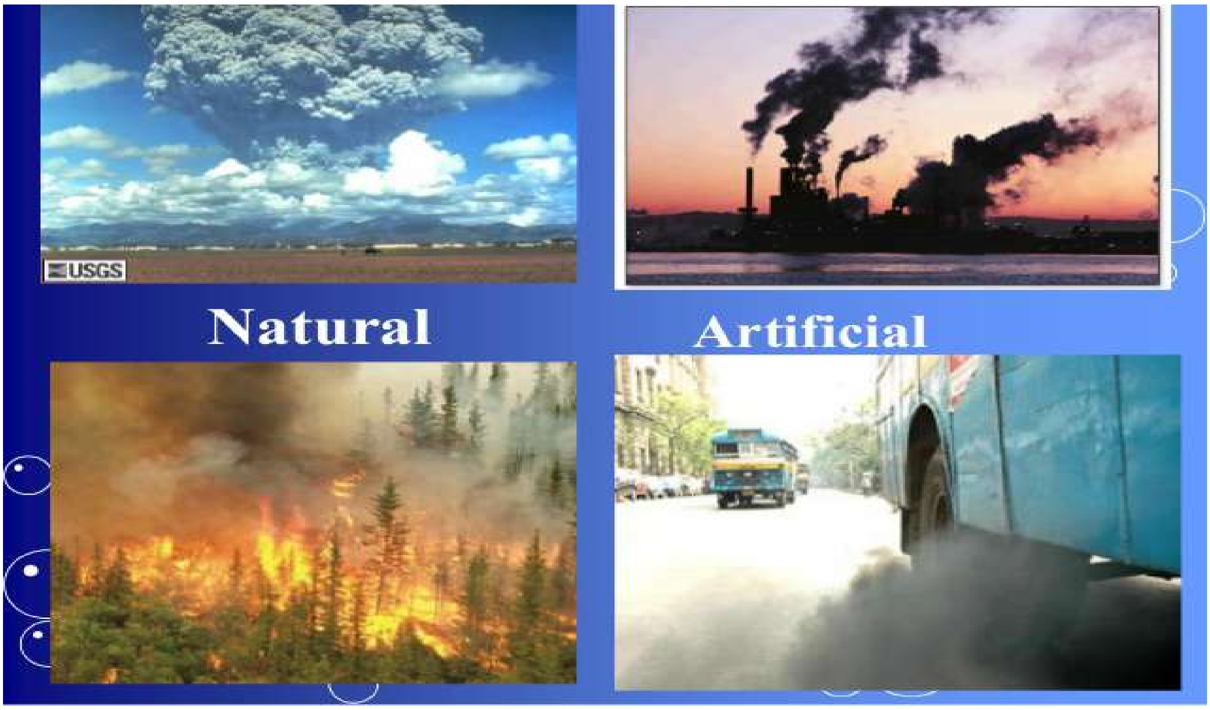
- These droplets can be formed from gas phase hydrolysis of halogenated acids (HCl, HF, HBr), metal halides, organohalides, sulfur trioxide (SO_3), and phosphorous pentoxide (P_2O_5).

Natural air pollutants:

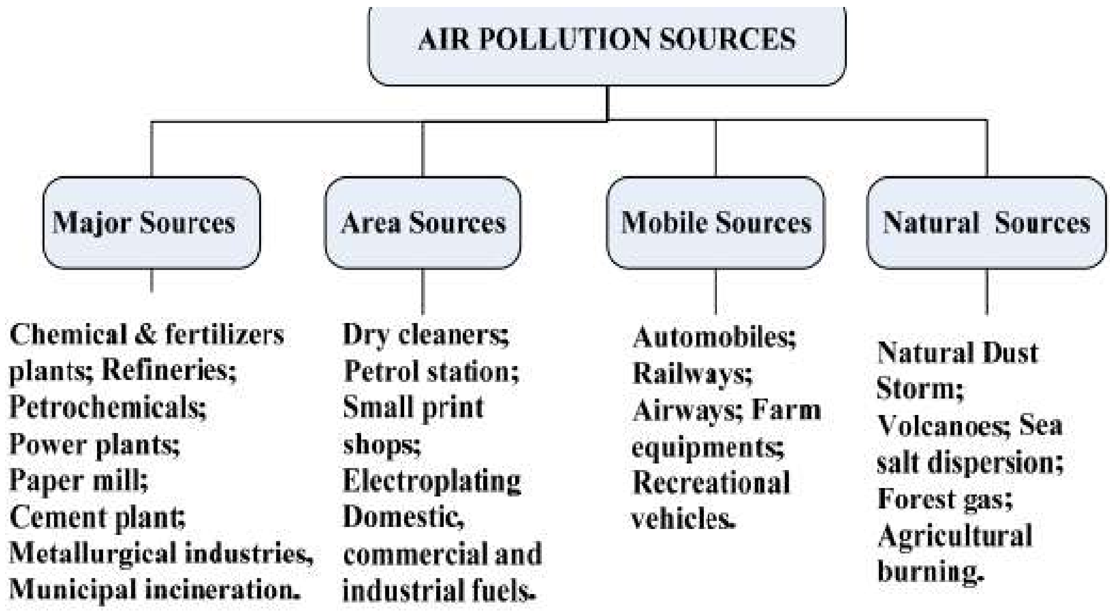
Natural events that pollute the air include forest fires, volcanic eruptions, wind erosion, **pollen** dispersal, evaporation of organic compounds and natural radioactivity.

Artificial air pollutants:

Artificial pollutants are those which are created by man. Ex: Thermal power plants, Vehicular emissions, Fossil fuel burning, agricultural activities etc.



Stationary and Mobile sources:



Mobile Sources: such as cars, buses, planes, trucks, and trains.

- Mobile sources account for more than half of all the air pollution

Stationary Sources: such as power plants, oil refineries, industrial facilities, and factories.

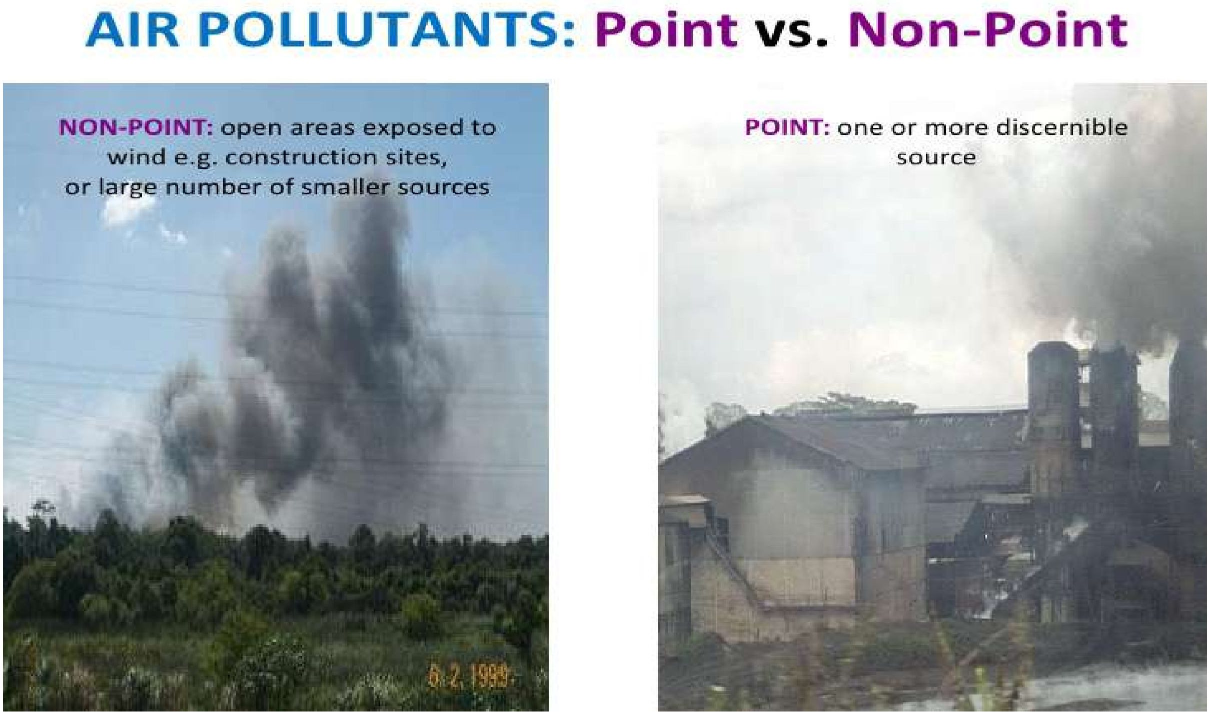
- Stationary sources, like power plants, emit large amounts of pollution from a single location, these are also known as point sources of pollution.

Area Sources: such as agricultural areas, cities, and wood burning fireplaces.

- Area sources are made up of lots of smaller pollution sources that aren't a big deal by themselves but when considered as a group can be.

Natural Sources: such as wind-blown dust, wildfires, and volcanoes

Point and Nonpoint sources pollution:



Ambient Air Quality Standards by WHO:

Air pollution is a major environmental risk to health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma. The lower the levels of air pollution, the better the cardiovascular and respiratory health of the population will be, both long- and short-term. The WHO Air Quality Guidelines: Global Update 2005 provide an assessment of health effects of air pollution and thresholds for health-harmful pollution levels. In 2016, 91% of the world population was living in places where the WHO air quality guidelines levels were not met.Ambient (outdoor air pollution) in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide in 2016.Some 91% of those premature deaths occurred in low- and middle-income countries, and the greatest number in the WHO South-East Asia and Western Pacific regions.Policies and investments supporting cleaner transport, energy-efficient homes, power generation, industry and better municipal waste management would reduce key sources of outdoor air pollution.In addition to outdoor air pollution, indoor smoke is a serious health risk for some 3 billion people who cook and heat their homes with biomass, kerosene fuels and coal.

Ambient Air Quality Standards by CPCB:

The Air (Prevention and Control of Pollution) Act 1981 was enacted by the Central Government with the objective of arresting the deterioration of air quality. The Air (Prevention and Control of Pollution) Act 1981 describes the main functions of the Central Pollution Control Board (CPCB) as follows:

To advise the Central Government on any matter concerning the improvement of the quality the air and the prevention, control and abatement of air pollution.

To plan and cause to be executed a nation-wide programme for the prevention, control and abatement of air pollution.

To provide technical assistance and guidance to the State Pollution Control Board.

To carry out and sponsor investigations and research related to prevention, control and abatement of air pollution.

To collect, compile and publish technical and statistical data related to air pollution; and To lay down and annul standards for the quality of air.

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

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1.____________ is the synchronym for a mixture of coal smoke and fog in the atmosphere.

2. ____________ refers to the rise in the world's annual average temperature due to air pollution.

3. PAN (in Air Pollution) stands for _____________.

4. The leak of _____________ gas was responsible for deaths in the Union Carbide Bhopal gas tragedy.

5. Fly ash is a ____________particle.

6. Pollution by _________________lead to photochemical smog in Los Angeles.

7. ______________is an example for mobile source of air pollution.

8. A highway is a _____________ type source of air pollution.

9. An adult human being breathes in about ___________ litres of air every day.

10. $PM_{2.5}$ with respect to air pollution means _____________.

II) Descriptive Questions

1. What is the chemical composition of air?
2. What are inert/noble gases? What is their % composition in air?
3. What is an air pollutant? Give any two examples.
4. What are some examples of natural air pollution? Can we control them?
5. What are some examples of primary and secondary air pollutants? .
6. What are some effects of man-made air pollution?
7. Explain the history of air pollution in London and how London became a clean city.
8. What are CFCs? Where are they used? Why are they being phased out?

B. Question testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. Which of the following type of coal produces the least air pollution

a. Peat

b. Lignite

c. Bituminous

d. Anthracite

2. Ozone is formed in the upper atmosphere by a ____________reaction with ultra violet radiation

a. Photochemical

b. Radio active

c. Electromagnetic

d. All of the above

3. Which of the following is a secondary pollutant?

a. CO_2

b. CO

c. O_3

d. SO_2

4. An example of mobile areal source of pollution is

a. Highway vehicles

b. Railroad locomotives

c. Channel vessels

d. Diesel Forklifts

5. Jet aircraft pollution leads to the thinning of

a. CO_2

b. SO_2

c. O_3

d. O_2

6. Which of the following options is a pair of primary air pollutants?
a. Sulphur oxide and ozone
b. Nitrogen oxide and peroxy acetyl nitrate
c. Sulphur oxide and hydrocarbon
d. Ozone and peroxy acetyl nitrate

7. The major photochemical oxidant is
a. Ozone
b. Hydrogen peroxide
c. Nitrogen oxides
d. Peroxy Acetyl Nitrate (PAN)

8. Air pollution from cooking on bio mass stoves can be reduced by
a. Providing exhaust chimneys
b. Ventilating the fire with more oxygen
c. Drying the fuel
d. All the above

9.Which of the following increases air pollution from motor cycles
a. Using adulterated fuel
b. Removing/modifying/replacing the standard exhaust (silencer)
c. Rash driving(accelerating and braking frequently)
d. All the above

10.Which of the following fuels causes maximum particulate pollution
a. Diesel
b. Kerosene
c. Petrol
d. LPG

II) Descriptive Questions

1. Briefly explain the significance of air pollution and its control.
2. What are the sources of air pollution? Classify them.
3. Explain how photo chemical smog is formed.
4. What is the difference between London smog and LA smog?
5. What is the difference between primary and secondary air pollutants?
6. Explain a point-mobile source of air pollution with example.
7. Explain how the gases in the atmosphere interact with hydrosphere, lithosphere and biosphere. Can we call these interactions as pollution?
8. Illustrate how stationary sources of pollution are causing ‘marble cancer’ to the surface of Taj Mahal. What can we do to stop the degradation of marble?

C: Analytical Questions

1. Visakhapatnam is the industrial city in AP. Based on air pollution episodes studied in this unit, describe possible pollution and its effects from various industries located in and around Visakhapatnam.
2. Explain the sequence of events in Bhopal gas tragedy and identify the technical and human

factors responsible for the accident.

3. WHO releases a list of the most polluted cities in the world from time to time. How many Indian cities are in the top 20 in the most recent ranking? Based on the list of cities you find in the list, analyse the reasons why they are so polluted.
4. In your daily life, identify all the steps that you could take to reduce air pollution directly and indirectly.

D. GATE Type questions.

1. **The most significant gaseous air pollutant is**
   a. **Carbon dioxide**
   b. **Oxygen**
   c. **Sulphur dioxide**
   d. **Nitrogen**

2. **The primary air pollutant which is formed due to incomplete combustion of organic matter is**
   a. **Methane**
   b. **Sulphur dioxide**
   c. **Ozone**
   d. **Carbon monoxide**
3. **Among the following the only secondary pollutants**
   a. **Sulphur dioxide**
   b. **Ozone**
   c. **Hydrocarbons**
   d. **Hydrogen sulphide**
4. **The most significant primary gaseous pollutant found in automobile exhaust is**
   a. **CO**
   b. **CO_2**
   c. **SO_2**
   d. **NO_2**

5. **The chemical compounds which are mainly responsible for producing are**
   a. **Hydro carbons**
   b. **Oxides of nitrogen**
   c. **Oxides of sulphur**

   a. **Only (i) and (ii)**
   b. **Only (i)and (iii)**
   c. **Only (ii) and (iii)**
   d. **(i), (ii) and (ii)**

6. **The secondary pollutant among the following**
   a. **Sulphur dioxide**
   b. **Methane**
   c. **Carbon monoxide**
   d. **Peroxy-Acetyl-Nitrate**

7. **The major photo chemical oxidant is**
   a. **Hydrogen peroxide**
   b. **Ozone**
   c. **Nitrogen oxides**
   d. **PAN**
8. **Aerosol is**

a. **Carbon particles of microscopic size**
b. **Dispersion of small solid or liquid particle in gaseous media**
c. **Finely divided particle of ash**
d. **Diffused liquid particles**

UNIT II

Air Pollution Meteorology

The earth's atmosphere is about 150 km deep. That thickness and volume sometimes are suggested to be enough to dilute all of the chemicals and particles thrown into it. However, 95% of this air mass is within 15 km of the earth's surface. This 15 km depth contains the air we breathe as well as the pollutants we emit. This layer, called the troposphere, is where we have our weather and air pollution problems. Weather patterns determine how air contaminants are dispersed and move through the troposphere, and thus determine the concentration of a particular pollutant that is breathed or the amount deposited on vegetation.

An air pollution problem involves three parts:

- The pollution source
- The transport or dispersion of the pollutant
- The recipient

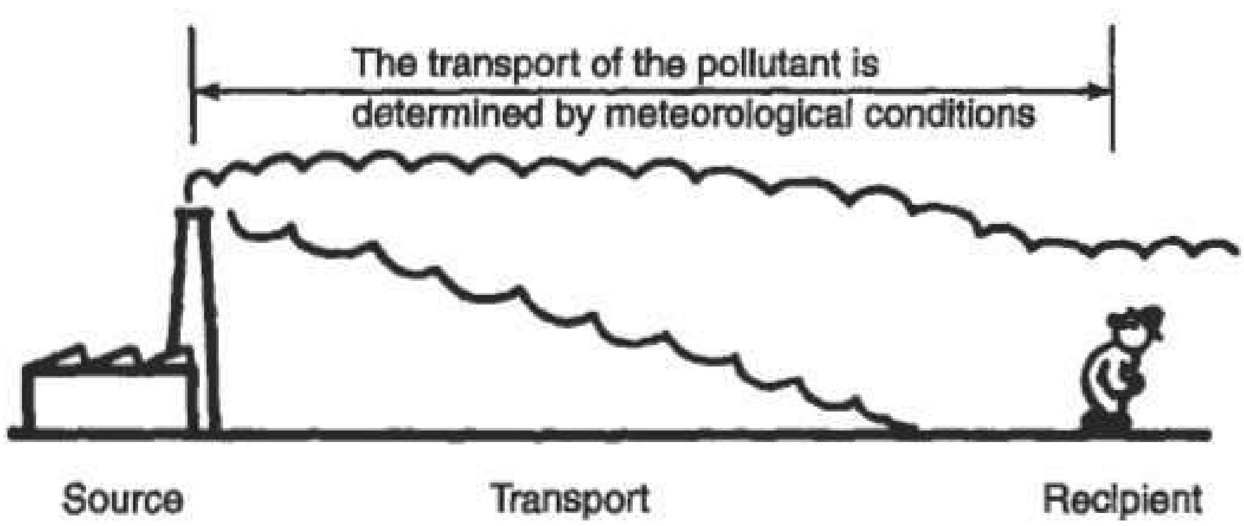


Figure 1. Meteorology of air pollutants.

This unit concerns itself with the transport mechanism: how the pollutants travel through the atmosphere. The environmental engineer should be conversant enough with some basic meteorology to be able to predict the dispersion of air pollutants.

BASIC METEOROLOGY

Pollutants circulate the same way the air in the troposphere circulates. Air movement is caused by solar radiation and the irregular shape of the earth and its surface, which causes unequal absorption of heat by the earth's surface and atmosphere. This differential heating and unequal absorption creates a dynamic system. The dynamic thermal system of the earth's atmosphere also yields differences in barometric pressure, associated with low-pressure systems with both hot and cold weather fronts.

Air movement around low-pressure fronts in the Northern Hemisphere is counterclockwise and vertical winds are upward, where condensation and precipitation take place. High-pressure systems bring sunny and calm weather – stable atmospheric conditions - with winds (in the Northern Hemisphere) spiralling clockwise and downward. Low - and high-pressure systems, commonly called cyclones and anticyclones, are illustrated in Fig. 2. Anticyclones are weather patterns of high stability, in which dispersion of pollutants is poor, and are often precursors to air pollution episodes. The high-pressure area indicates a region of stable air, where pollutants build up and do not disperse.

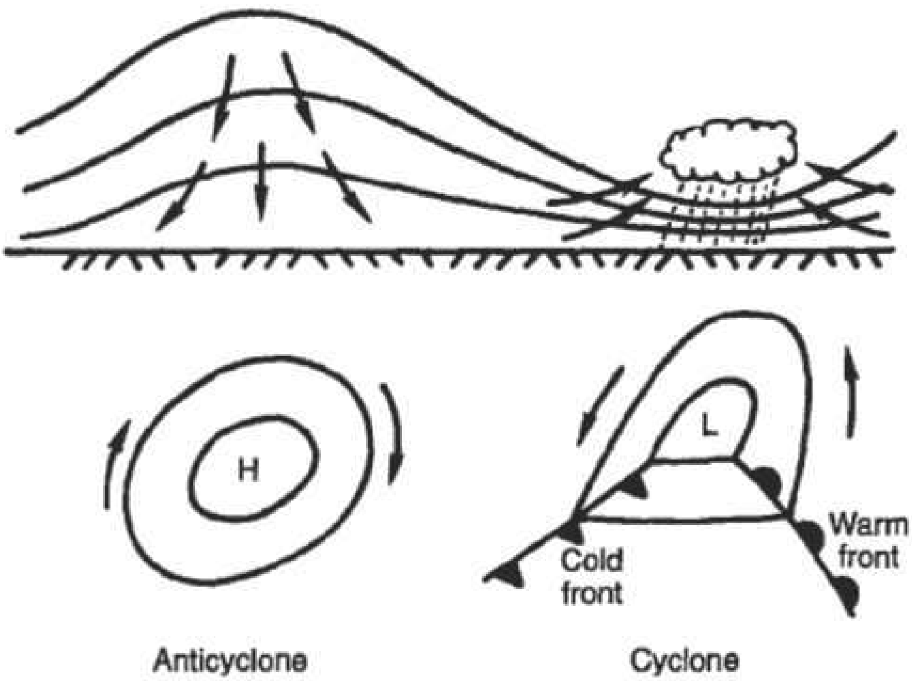


Figure 2. Anticyclone and cyclone.

Air quality management involves both control of air pollution sources and effective dispersion of pollutants in the atmosphere.

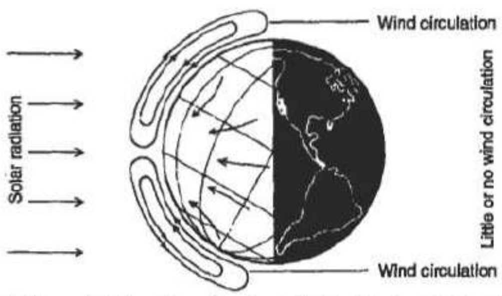
HORIZONTAL DISPERSION OF POLLUTANTS

The earth receives light energy at high frequency from the sun and converts this to heat energy at low frequency, which is then radiated back into space. Heat is transferred from the earth's surface by radiation, conduction, and convection.

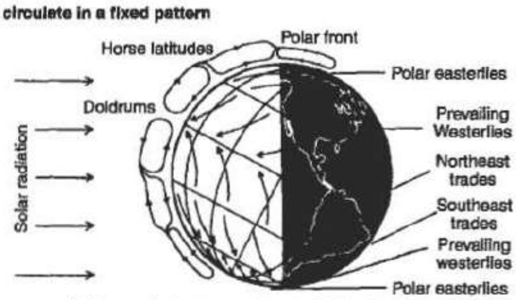
Radiation is direct transfer of energy and has little effect on the atmosphere. Conduction is the transfer of heat by physical contact (the atmosphere is a poor conductor since the air molecules are relatively far apart). Convection is transfer of heat by movement of warm air masses.

Solar radiation warms the earth and thus the air above it. This heating is most effective at the equator and least at the poles. The warmer, less dense air rises at the equator and cools, becomes more dense, and sinks at the poles. If the earth did not rotate then the surface wind pattern would be from the poles to the equator. However, the rotation of the earth continually presents new surfaces to be warmed, so that a horizontal air pressure gradient exists as well as the vertical pressure gradient.

The resulting motion of the air creates a pattern of winds around the globe, as shown by Fig. 3. Seasonal and local temperature, pressure and cloud conditions, and local topography complicate the picture. Land masses heat and cool faster than water so that shoreline winds blow out to sea at night and inland during the day.



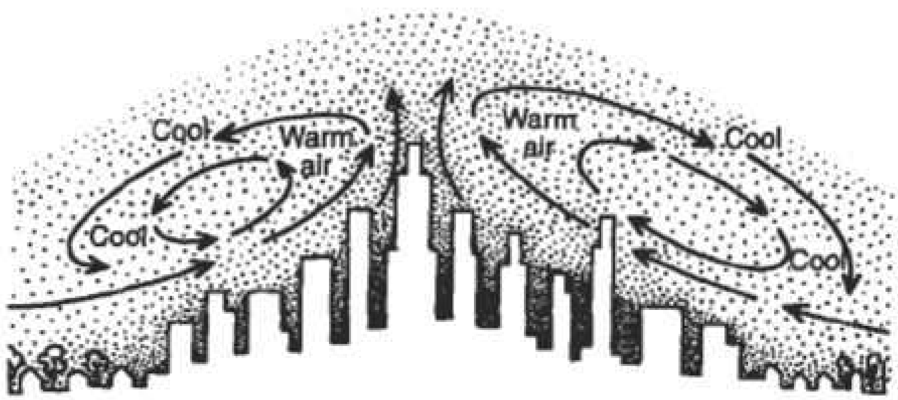
A. If the earth did not turn, the air would circulate in a fixed pattern



B. The earth turns, creating variable wind patterns

Figure 3. Global wind patterns.

Valley winds result from cooling of air high on mountain slopes. In cities, brick and concrete buildings absorb heat during the day and radiate it at night, creating a heat island (Fig. 4), which sets up a self-contained circulation called a haze hood from which pollutants cannot escape. Horizontal wind motion is measured as wind velocity. Wind velocity data are plotted as a wind rose, a graphic picture of wind velocities and the direction from which the wind came. The wind rose in Fig. 5 shows that the prevailing winds were from the southwest.



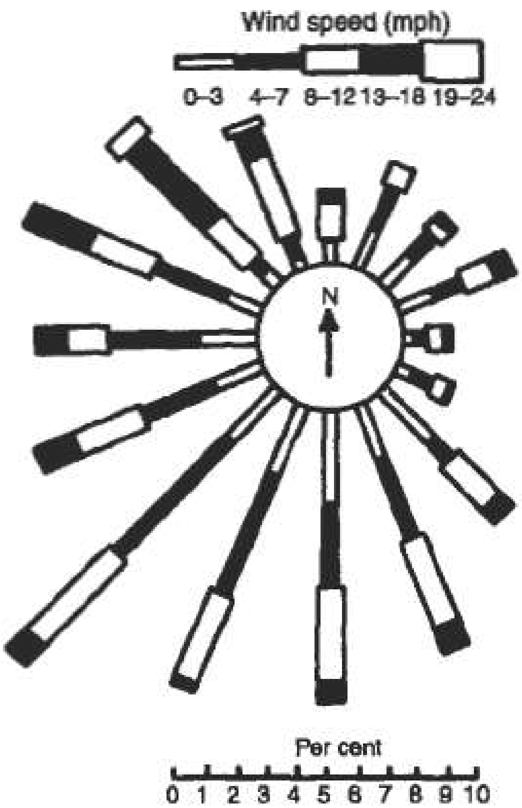


Figure 4. Heat island formed over a city.

Figure 5. Typical wind rose.

The three features of a wind rose are:

1.The orientation, which shows the direction from which the wind came
2.The width of each segment, which is proportional to the wind speed
3.The length of each segment, which is proportional to the percent of time that wind at that particular speed was coming from that particular direction.

Air pollution enforcement engineers sometimes use a pollution rose, a variation of a wind rose in which winds are plotted only on days when the air contamination level exceeds a given amount.
Figure 6 shows pollution roses at three points plotted only for days when the SO2 level exceeded 250 µg/m3.

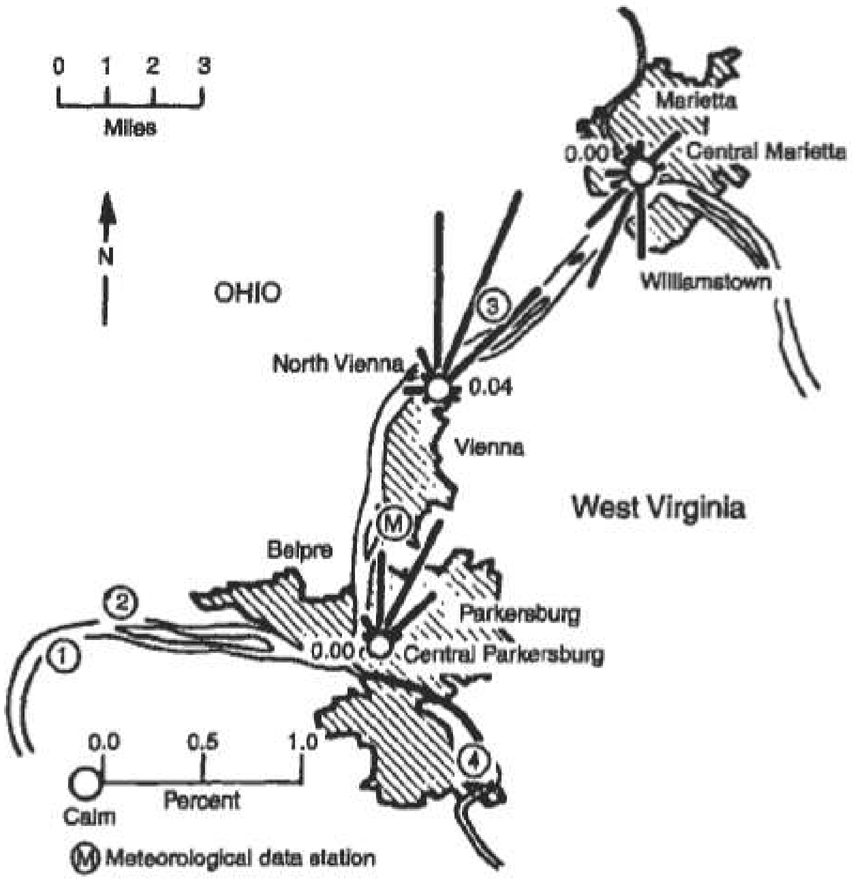


Figure 6. Pollution roses for SO2 concentrations greater than 250 250 µg/m3. The four chemical plants are the suspected sources, but the roses clearly point to Plant 3, identifying

it as the primary culprit.

Note that because the roses indicate the directions from which the wind is coming the apparent primary pollution source is plant 3. Wind is probably the most important meteorological factor in the movement and dispersion of air pollutants, or, in simple terms, pollutants move predominantly downwind.

VERTICAL DISPERSION OF POLLUTANTS

As a parcel of air in the earth's atmosphere rises through the atmosphere, it experiences decreasing pressure and thus expands. This expansion lowers the temperature of the air parcel, and therefore the air cools as it rises. *The rate at which dry air cools as it rises is called the dry adiabatic lapse rate and is independent of the ambient air temperature.* The term "adiabatic" means that there is no heat exchange between the rising parcel of air under consideration and the surrounding air. The dry adiabatic lapse rate may be calculated from basic physical principles. where T = temperature and z = altitude. The actual measured rate at which air cools as it rises is called the ambient or prevailing lapse rate. The relationships between the ambient lapse rate and the dry adiabatic lapse rate essentially determine the stability of the air and the speed with which pollutants will disperse. These relationships are shown in Fig. 7.

$$dT/dz|_{\text{dry-adiabatic}} = -9.8°\text{C/km},$$

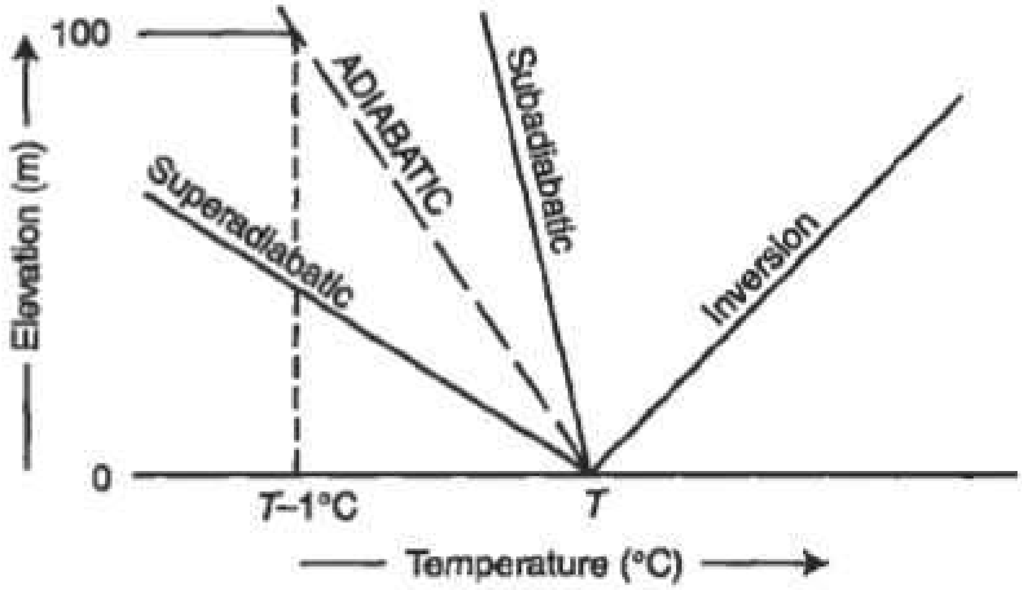


Figure 7. Ambient lapse rates and the dry adiabatic lapse rate.

When the ambient lapse rate is exactly the same as the dry adiabatic lapse rate, the Superadiabatic conditions prevail when the air temperature drops more than 9.8 ° C/Km (1 ° C/100m). Subadiabatic conditions prevail when the air temperature drops at a rate less than 9.8 ° C/Km. A special case of subadiabatic conditions is the temperature inversion, when the air temperature actually increases with altitude and a layer of warm air exists over a layer of cold air. Superadiabatic atmospheric conditions are unstable and favour dispersion; subadiabatic conditions are stable and result in poor dispersion; inversions are extremely stable and trap pollutants, inhibiting dispersion. These conditions may be illustrated by the following example, illustrated in Fig. 8:

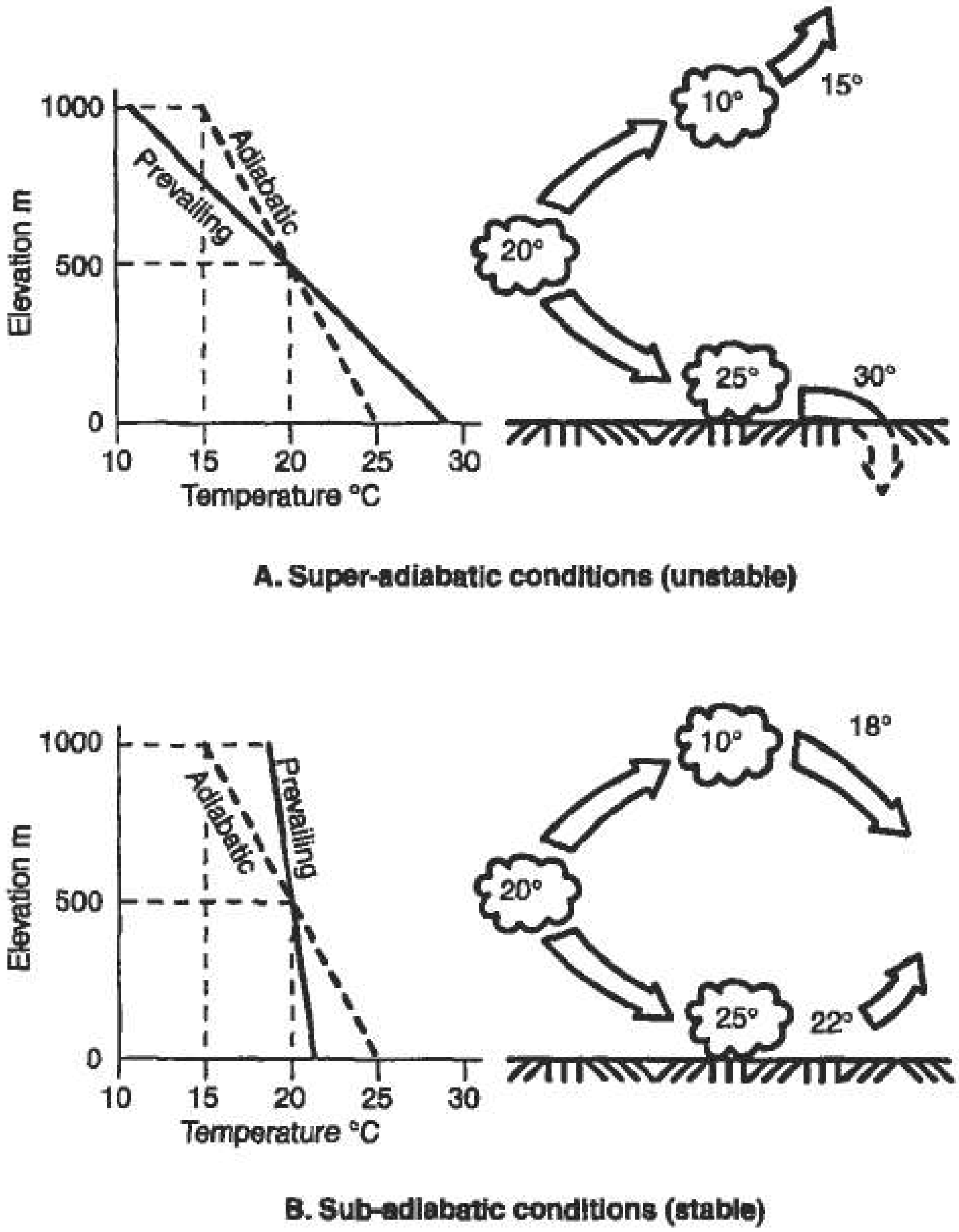


Figure 8. Stability and vertical air movement.

Problem: The air temperature at an elevation of 500 m is 20°C, and the atmosphere is superadiabatic, the ground level temperature is 30°C and the temperature at an elevation of 1 km is 10°C. The (superadiabatic) ambient lapse rate is -20°C/km. If a parcel of air at 500 m moves up adiabatically to 1 km, what will be its temperature? *Solution*: According to the dry adiabatic lapse rate of - 9.8 °C/Km the air parcel would cool by 4.9 °C to about 15°C. However, the temperature at 1 km is not 15°C but 10°C. Our air parcel is 5°C warmer than the surrounding air and will continue to rise. In short, under subadiabatic conditions, a rising parcel of air keeps right on going up. Similarly, if our parcel were displaced downward to, say, 250m, its temperature would increase by 2.5 °C to 22.5 °C. The ambient temperature at 250 m, however, is 25 °C, so that our parcel of air is now cooler than the surrounding air and keeps on sinking. There is no tendency to stabilize; conditions favour instability. Now let us suppose that the ground level temperature is 22 ° C, and the temperature at an elevation of 1 km is 15°C. The (subadiabatic) ambient lapse rate is now -7 °C/Km. If our parcel of air at 500 m moves up adiabatically to 1 km, its temperature would again drop by 4.9 °C to about 15°C, the same as the temperature of the surrounding air at 1 km. Our air parcel would cease rising, since it would be at the same density as the surrounding air. If the parcel were to sink to 250 m, its temperature would again be 22.5 C, and the ambient temperature would be a little more than 20°C.

The air parcel is slightly warmer than the surrounding air and tends to rise back to where it was. In other words, its vertical motion is damped, and it tends to become stabilized, subadiabatic conditions favour stability and limit vertical mixing.

Figure 9 is an actual temperature sounding for Los Angeles. Note the beginning of an inversion at about 1000 ft that puts an effective cap on the city and holds in the air pollution. This type of inversion is called a subsidence inversion, caused by a large mass of warm air subsiding over a city.

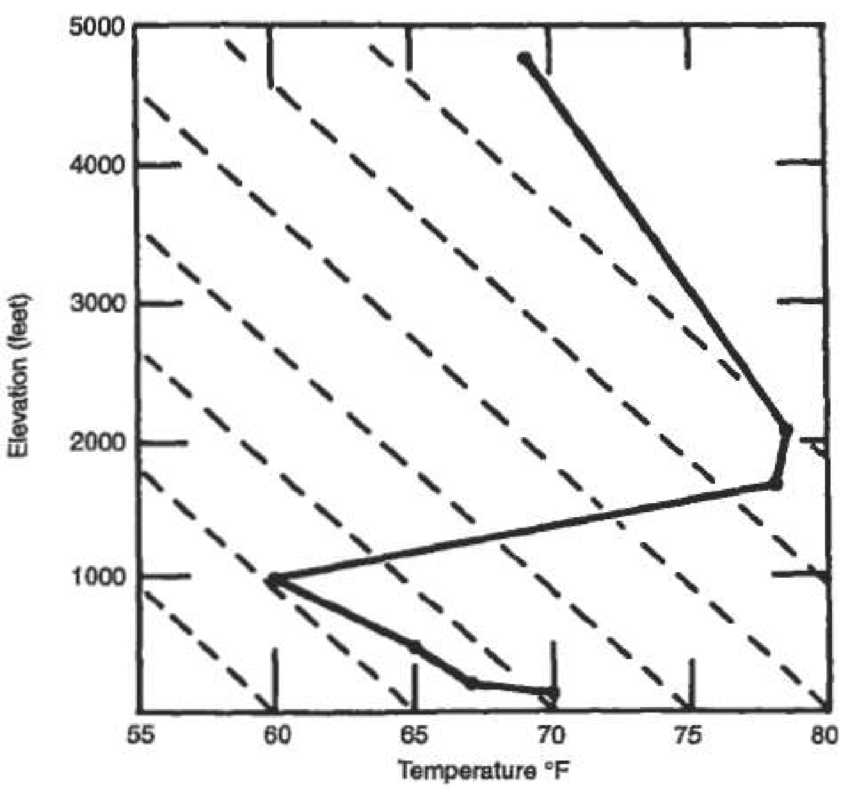


Figure 9. Temperature sounding for Los Angeles, 4 PM, October 1962. The dotted lines

show the dry adiabatic lapse rate.

A more common type is the radiation inversion, caused by radiation of heat from the earth at night. As heat is radiated, the earth and the air closest to it cool, and this cold air is trapped under the warm air above it (Fig. 10).

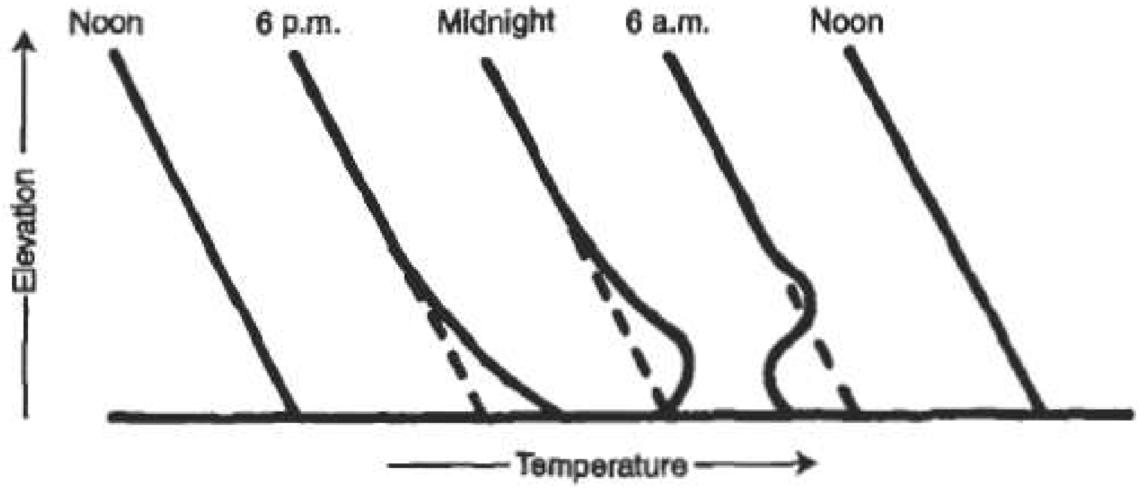


Figure 10. Typical ambient lapse rates during a sunny day and clear night.

Pollution emitted during the night is caught under the "inversion lid." Atmospheric stability may often be recognized by the shapes of plumes emitted from smokestacks as seen in Figs. 11 and 12.

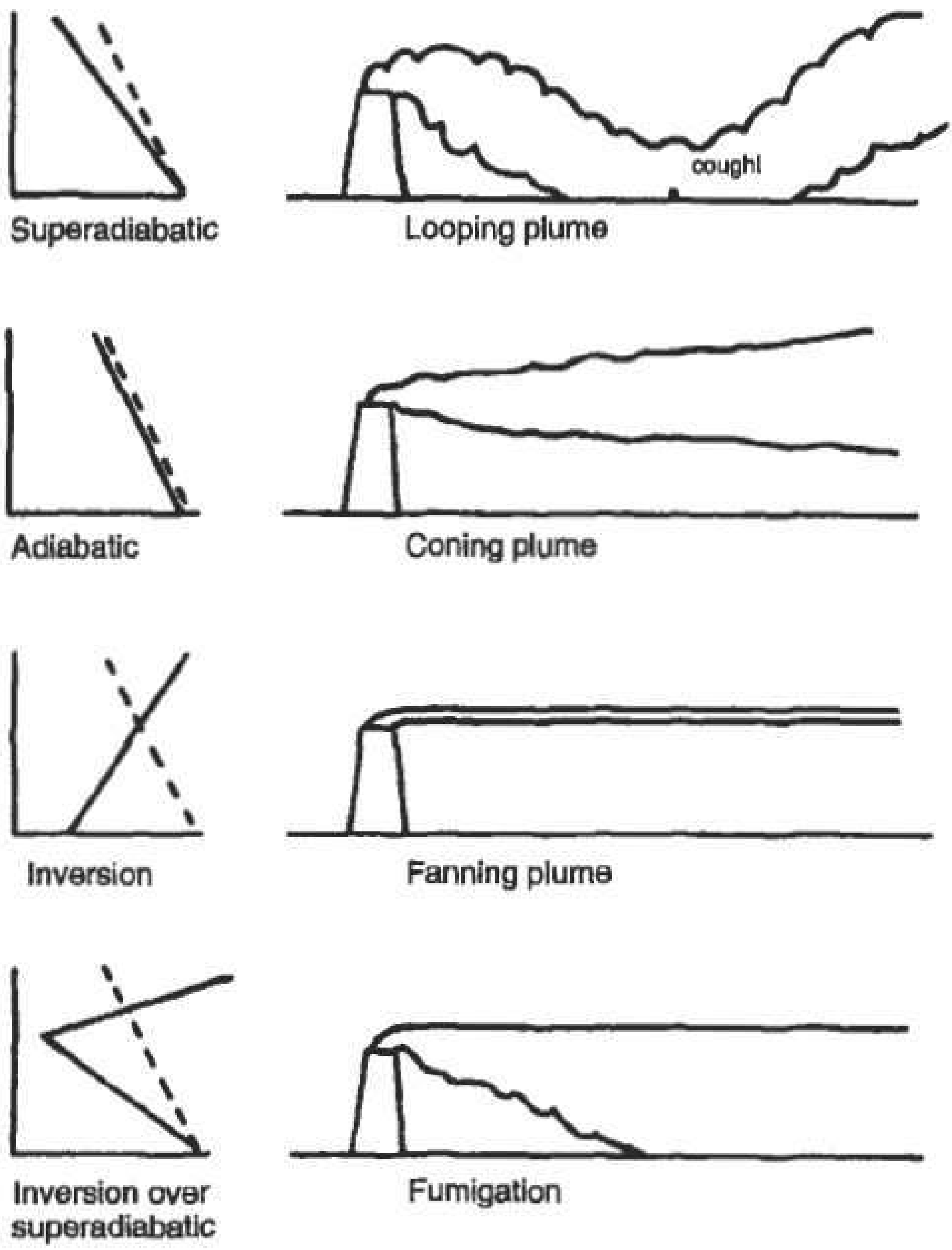


Figure 11. Plume shapes and atmospheric stability.

Figure 12. Iron oxide dust looping plume from a steel mill

Neutral stability conditions usually result in coning plumes, while unstable (superadiabatic) conditions result in a highly dispersive looping plume. Under stable (subadiabatic) conditions, the funning plume tends to spread out in a single flat layer. One potentially serious condition is called fumigation, in which pollutants are caught under an inversion and are mixed owing to strong lapse rate. A looping plume also produces high ground-level concentrations as the plume touches the ground. Assuming adiabatic conditions in a plume allows estimation of how far it will rise or sink, and what type of plume it will be during any given atmospheric temperature condition, as illustrated by problem below.

Problem: A stack l00 m tall emits a plume whose temperature is 20°C. The temperature at the ground is 19°C. The ambient lapse rate is -4.5 °C /km up to an altitude of 200 m. Above this the ambient lapse rate is +20°C /km. Assuming perfectly adiabatic conditions, how high will the plume rise and what type of plume will it be? Figure 13 shows the various lapse rates and temperatures.

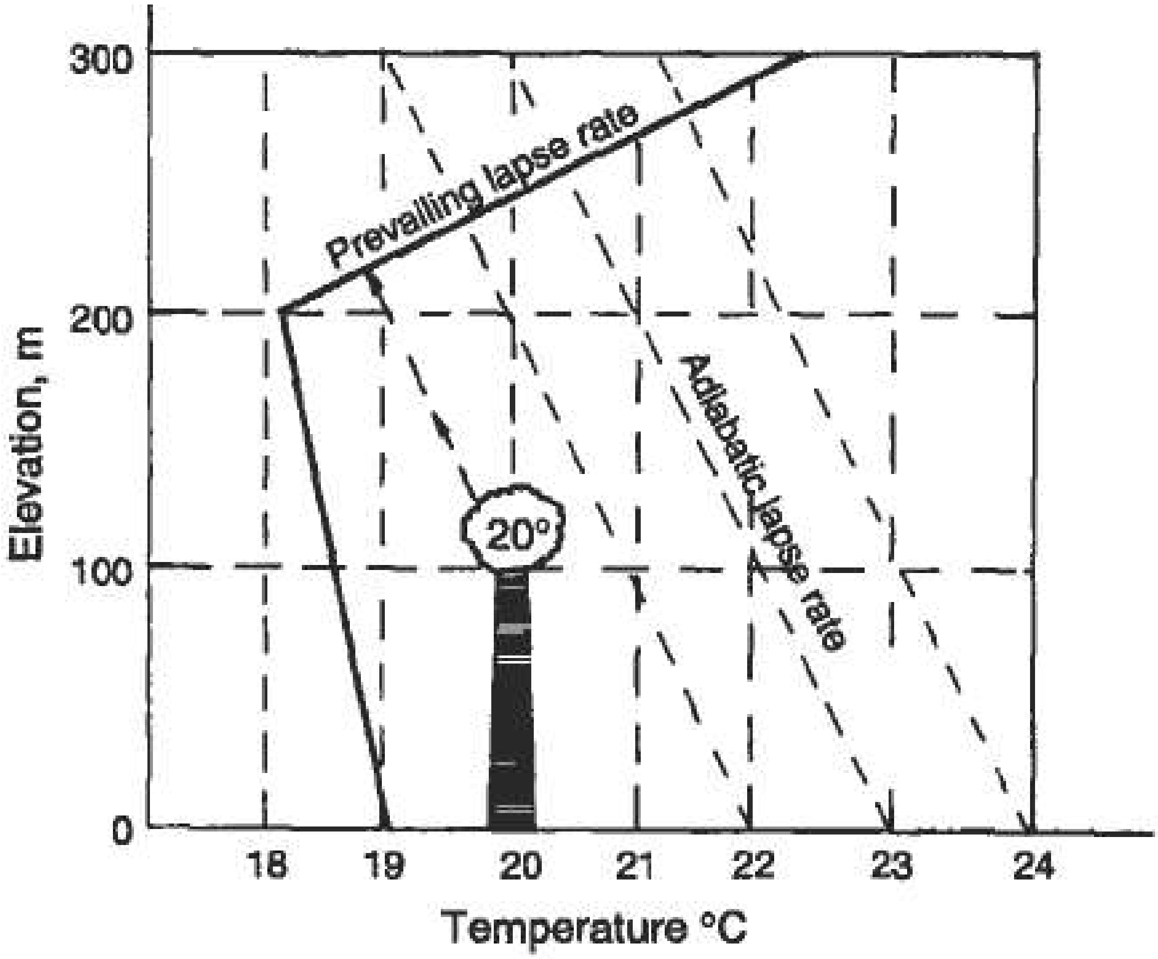


Figure 13. Atmospheric conditions in problem.

The plume is assumed to cool at the dry adiabatic lapse rate 10°C km. The ambient lapse rate below 200 m is subadiabatic, the surrounding air is cooler than the plume, so it rises, and cools as it rises. At 225 m, the plume has cooled to 18.7°C, but the ambient air is at this temperature also, and the plume ceases to rise. Below 225 m, the plume would have been slightly coning. It would not have penetrated 225 m.

Effect of Water (humidity) in the Atmosphere

The dry adiabatic lapse rate is characteristic of dry air. Water in the air will condense or evaporate, and in doing so will release or absorb heat, respectively, making calculations of the lapse rate and atmospheric stability complicated. In general, as a parcel of air rises, the water vapor in that parcel will condense and heat will be released. The rising air will therefore cool more slowly as it rises; the wet adiabatic lapse rate will in general be less negative than the dry adiabatic lapse rate. The wet adiabatic lapse rate has been observed to vary between -6.5 and - 3.5°C /Km.

Water in the atmosphere affects air quality in other ways as well. Fogs are formed when moist air cools and the moisture condenses. Aerosols provide the condensation nuclei, so that fogs tend to occur more frequently in urban areas. Serious air pollution episodes are almost always accompanied by fog (remember that the roots of the word “smog” are “smoke” and “fog”). The tiny water droplets in fog participate in the conversion of SO3 to H2SO4. Fog sits in valleys and stabilizes inversions by preventing the sun from warming the valley floor, thus often prolonging air pollution episodes.

MODELLING ATMOSPHERIC DISPERSION OF POLLUTANTS

Dispersion is the process by which contaminants move through the air and a plume spreads over a large area, thus reducing the concentration of the pollutants it contains. The plume spreads both horizontally and vertically. If it is a gaseous plume, the motion of the molecules follows the laws of gaseous diffusion. The most commonly used model for the dispersion of gaseous air pollutants is the Gaussian model developed by Pasquill, in which gases dispersed in the atmosphere are assumed to exhibit ideal gas behaviour.

The principles on which the model is based are:

- The predominant force in pollution transport is the wind; pollutants move predominantly downwind.
- The greatest concentration of pollutant molecules is along the centre line.
- Molecules diffuse spontaneously from regions of higher concentration to regions of lower concentration.
- The pollutant is emitted continuously, and the emission and dispersion process is steady state.

Figure 14 shows the fundamental features of the Gaussian dispersion model, with the geometric arrangement of source, wind, and plume.

We can construct a Cartesian coordinate system with the emission source at the origin and the wind direction along the x axis. Lateral and vertical dispersions are along the y and z axes, respectively.

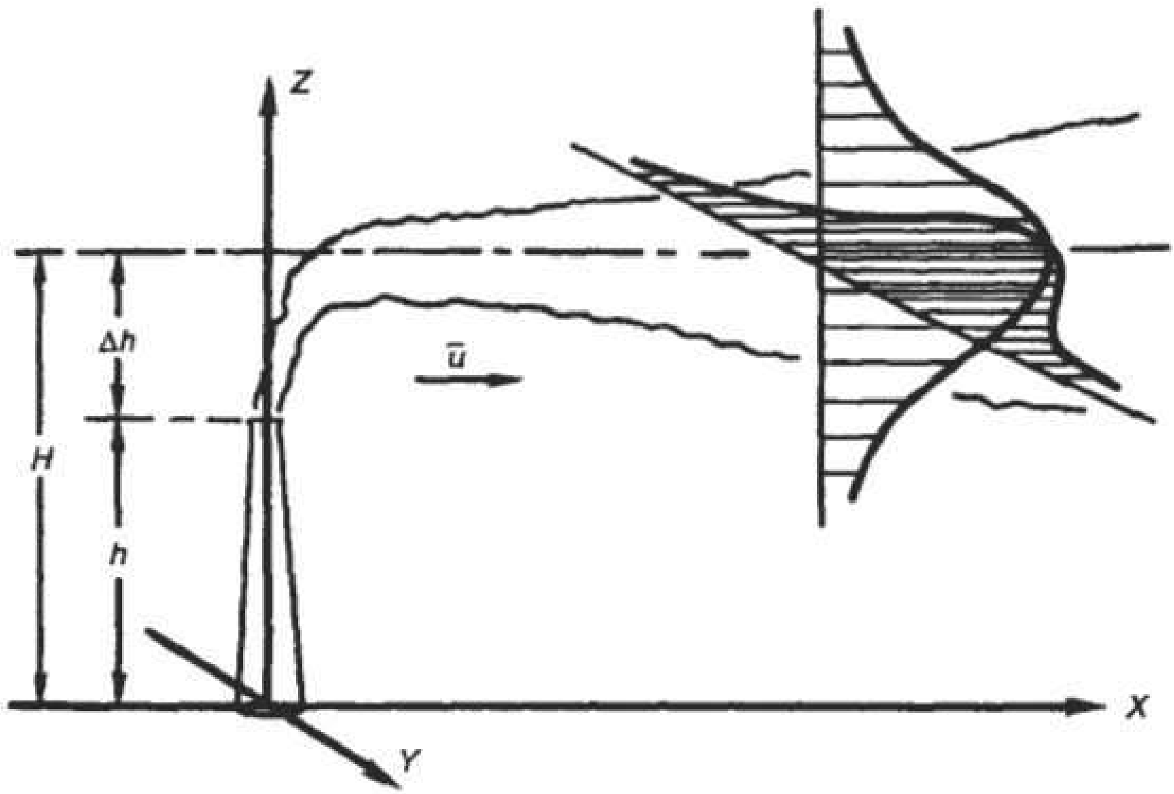


Figure 14. Gaussian dispersion model.

As the plume moves downwind, it spreads both laterally and vertically away from the plume centreline as the gas molecules move from higher to lower concentrations. Cross sections of the pollutant concentration along both the y and the z axes thus have the shape of Gaussian curves, as shown in Fig. 14. Since stack gases are generally emitted at temperatures higher than ambient, the buoyant plume will rise some distance before beginning to travel downwind. The sum of this vertical travel distance and the geometric stack height is H, the effective stack height. The source of the pollutant plume is, in effect, a source elevated above the ground at elevation Z=H
and the downwind concentration emanating from this elevated source may be written where C(x, y, z) is the concentration at some point in space with coordinates x, y, z,

Q = the emission rate of the pollution source (in g/s), u = the average wind speed in (m/s), σy = the standard deviation of the plume in the y direction (m), and σz, = the standard deviation of the plume in the z direction (m). The units of concentration are grams per cubic meter (g/cu.m). Since pollution concentrations are usually measured at ground level, that is, for z = 0, the Eq. usually reduces to the one below. This equation takes into account the reflection of gaseous pollutants from the surface of the ground.

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left(\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)\right)$$

We are usually interested in the greatest value of the ground level concentration in any direction, and this is the concentration along plume centreline; that is, for y = 0. In this case, the Eq. reduces to

$$C(x, y, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left(\exp\left(-\frac{(H)^2}{2\sigma_z^2}\right)\right)$$

Finally, for a source of emission at ground level, H = 0, and the ground level concentration of pollutant downwind along the plume centreline is given by

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right)$$

For a release above ground level the maximum downwind ground level concentration occurs along the plume centreline when the following condition is satisfied:

$$C(x, 0, 0) = \frac{Q}{\pi u \sigma_y \sigma_z}$$

The standard deviations σy, and σz, are measures of the plume spread in the crosswind (lateral) and vertical directions, respectively.

$$\sigma_z = \frac{H}{\sqrt{2}}.$$

They depend on atmospheric stability and on distance from the source. Atmospheric stability is classified in categories A through F, called stability classes. Table 1 shows the relationship between stability class, wind speed, and sunshine conditions.

Wind speed at 10 m (m/s)	Day Incoming solar radiation			Night Thin overcast	
	Strong	Moderate	Slight	1/2 low cloud	3/8 cloud
<2	A	A–B	B		
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	E
>6	C	D	D	D	D

Table 1. Atmospheric Stability under Various Conditions

Class A is the least stable; Class F is the most stable. In terms of ambient lapse rates, Classes A, B, and C are associated with superadiabatic conditions; Class D with neutral conditions; and Classes E and F with subadiabatic conditions. A seventh, Class G, indicates conditions of extremely severe temperature inversion, but in considering frequency of occurrence is usually combined with Class F. Urban and suburban populated areas rarely achieve stability greater than Class D, because of the heat island effect; stability classes E and F are found in rural and unpopulated areas. Values for the lateral and vertical dispersion constants, σy, and σz, are given in Figs. 15 and 16.

Use of the figures is illustrated in the following Problem: An oil pipeline leak results in emission of l00g/h of H2S. On a very sunny summer day, with a wind speed of 3.0 m/s, what will be the concentration of H2S 1.5 km directly downwind from the leak?

Solution: From Table 1, we may assume Class B stability. Then, from Fig. 15, at x = 1.5 km, σy is approximately 210m and, from Fig. 16, σz is approximately 160m, and Q = 100 g/h = 0.0278 g/s. Applying the Eq., we have

$$C(x,0,0) = \frac{Q}{\pi u \sigma_y \sigma_z}$$

$$C(1500,0,0) = \frac{0.0278\,\mathrm{g/s}}{\pi(3.0\,\mathrm{m/s})(210\,\mathrm{m})(160\,\mathrm{m})} = 8.77 \times 10^{-8}\,\mathrm{g/m^3} = 0.088\,\mu\mathrm{g/m^3}$$

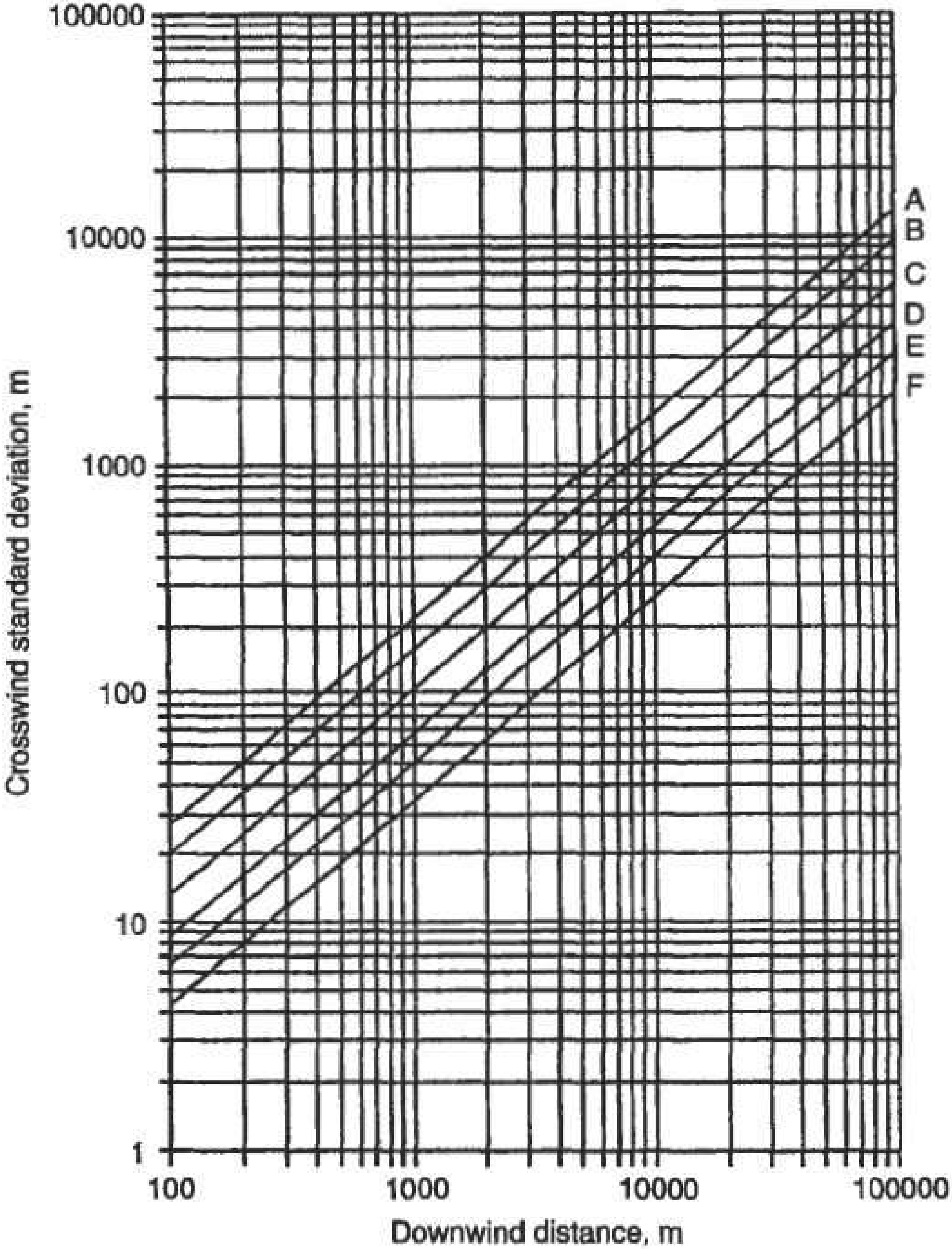


Figure 15. Standard deviation or dispersion coefficient, σy, in the crosswind direction as a function of downwind distance (Wark and Warner 1986).

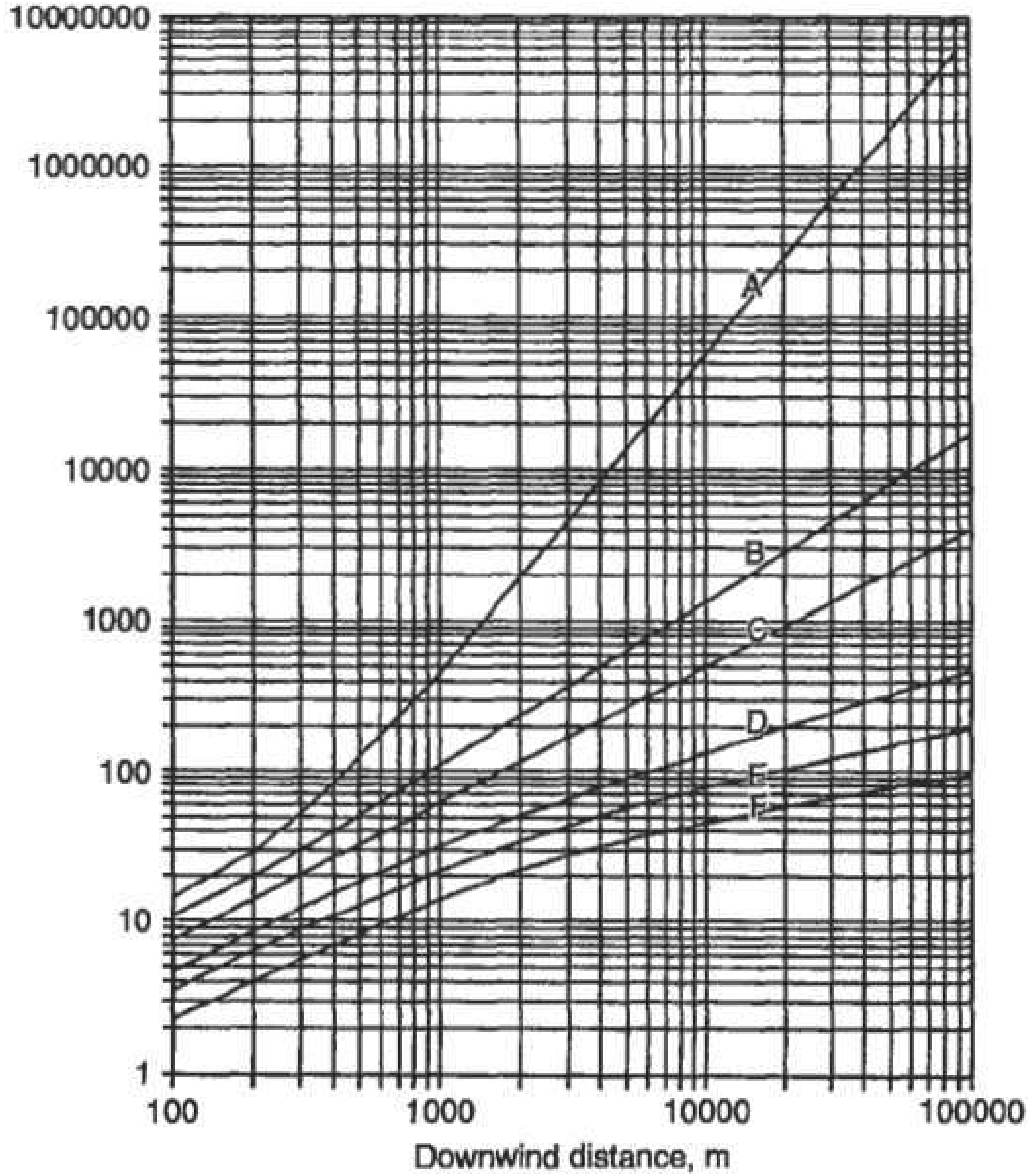


Figure 16. Standard deviation or dispersion coefficient, σz, in the vertical direction as a function of downwind distance (Wark and Warner 1986).

Problem: A coal-burning electric generating plant emits 1.1 kg/min of SO2 from a stack with an effective height of 60m. On a thinly overcast evening, with a wind speed of 5.0 m/s , what will be the ground level concentration of SO2 500 m directly downwind from the stack?

From Table 1, we may assume Class D stability. Then, from Fig. 15, at x = 0.5 km, σy is approximately 35 m and σz, is approximately 19 m, and Q = 1.10 kg/min = 18 g/s.
In this problem, the release is elevated, and H = 60 m. Applying the Eq., we have

$$C(x,0,0)=\frac{Q}{\pi u\sigma_y\sigma_z}\exp\left(\frac{-H^2}{2\sigma_z^2}\right)$$

$$C(0.5,0,0)=\frac{18\ \text{g/s}}{\pi(5\ \text{m/s})(35\ \text{m})(19\ \text{m})}\exp\left(\frac{-(60)^2}{2(19)^2}\right)=11.8\times10^{-6}\ \text{g/m}^3,$$

Variation of Wind Speed With Elevation

The model used so far assumes that the wind is uniform and unidirectional, and that its velocity can be estimated accurately. These assumptions are not realistic.Wind direction shifts and wind speed varies with time as well as with elevation. The variation of wind speed with elevation can be approximated by a parabolic wind velocity profile. That is, the wind speed u at an elevation h may be calculated from the measured wind speed uo at a given elevation ho using the relationship. The exponent n, called the stability parameter, is an empirically determined function of the atmospheric stability, and is given in Table 2.

$$u=u_0\left(\frac{h}{h_0}\right)^n$$

Stability condition	n
Large lapse rate (Classes A, B, C)	0.20
Zero or small lapse rate (Class D)	0.25
Moderate inversion (Class E)	0.33
Strong inversion (Classes F and G)	0.50

[a] From Wark and Warner (1986).

Table 2. Relationship between the Stability Parameter and Atmospheric stability

Wind is often measured in weather stations at an elevation of 10 m above ground level.

Effective Stack Height

The effective stack height is the height above ground at which the plume begins to travel downwind, the effective release point of the pollutant and the origin of its dispersion. A number of empirical models exist for calculating the plume rise h - the height above the stack to which the plume rises before dispersing downwind. Three equations that give a reasonably accurate estimate of plume rise have been developed by Carson and Moses (1969) for different stability conditions. For superadiabatic conditions for neutral stability and for subadiabatic conditions

$$\Delta h = 3.47\frac{V_s d}{u} + 5.15\frac{Q_h^{0.5}}{u}; \quad \Delta h = 0.35\frac{V_s d}{u} + 2.64\frac{Q_h^{0.5}}{u}$$

where
V, = stack gas exit speed (in m/s) ,
d = stack diameter (in m), and
Qh = heat emission rate from the stack (in kJ/s).
As before, length is in meters and time is in seconds, and the heat emission rate is measured in kilojoules per second. Problem: A power plant has a stack with a diameter of 2 m and emits gases with a stack exit velocity of 15 m/s and a heat emission rate of 4,800 kJ/S. The wind speed is 5 m/s . Stability is neutral. Estimate the plume rise. If the stack has a geometric height of 40 m, what is the effective stack height?

$$\Delta h = -1.04\frac{V_s d}{u} + 2.24\frac{Q_h^{0.5}}{u}$$

$$\Delta h = 0.35\frac{(15)(2)}{5} + 2.64\frac{\sqrt{4800}}{5} = 38.7\,\text{m}$$

$$H = h_g + h$$

$$H = 40\,\text{m} + 38.7\,\text{m} = 78.7\,\text{m}.$$

a

The accuracy of plume rise and dispersion analysis is not very good. Uncalibrated models predict ambient concentrations to within an order of magnitude at best. To ensure reasonable validity and reliability, the model should be calibrated with measured ground level concentrations. The model discussed applies only to a continuous, steady point source of emission. Discrete discontinuous emissions or puffs, larger areas that act as sources, like parking lots, and line sources, like highways, are modeled using variants of the Gaussian approach, but the actual representation used in each case is quite different.

Computer Models for Assessing Atmospheric Dispersion

A number of computer models that run on a desktop PC exist for assessing atmospheric dispersion of pollutants. These are essentially codifications of the Gaussian dispersion equations that solve the equations many times and output an isopleth plot.

Some models are:

DEPOSlTION 2.0 (U.S. Nuclear Regulatory Commission NUREG/GR- 0006, 1993)
CAP88-PC (US. Department of Energy, ER 8.2, GTN, 1992)
RISKIND (Yuan et al. 1993)
HAZCON (Sandia National Laboratories 1991)
TRANSAT (Sandia National Laboratories 1991)
HOTSPOT (Lawrence Livermore National Laboratory, 1996) MACCS 2 (Sandia National Laboratories, 1993)

Syllabus of UNIT-III: AIR POLLUTION CONTROL AND MONITORING
Control of particulates - control at source, process changes, equipment modifications, design and operation of control equipment's - settling chambers, centrifugal separators, filters - dry and wet scrubbers, electrostatic precipitators. Thermodynamics and Kinetics of Air-Pollution Applications in the removal of gases like SO_x, NO_x, CO, HC
Computation of Air-Fuel Ratio, control of products of combustion

Objective of this Unit: To understand the process of separating particulates from gaseous emissions using various strategies and equipment's and basics of fuel combustion and formation of polluting gases in various energy conversion processes.

Learning outcome: After completing this unit, the student will be able to appreciate the significance of fuel, air and temperature combinations in various energy conversion processes to achieve the goals of energy efficiency and pollution control.

Everyday about half-a-million tonne of particulates (of sizes ranging from 100 to 0.1 microns and even less) are released into the atmosphere by anthropogenic sources in India. Particulates on micro-scale cause adverse effects on human health, material and vegetation and on a macro-scale, affect the earth's - atmosphere. Particulates present in air in the form of aerosols, dusts, mist, smoke, smog, smaze or cloud, pose a potential pollution hazard and the already worsened situation demands an immediate relief by means of a proper particulate control technology. There are three broad approaches to the control of particulates — dilution in the atmosphere, control at source and control by using pollution control equipment.

Dilution:

Dilution of particulates and gases can be accomplished by the use of tall stacks. Pollutants released from taller stacks disperse easily and hence low ground level concentrations are observed. Tall stacks penetrate the inversion layer and disperse the contaminants easily so that the ground level concentrations are less harmful. Thus, dilution is only a short-term control measure and tends to bring about highly undesirable long-range effects.

In India, a minimum stack height of 30 m is to be provided. Similarly, the minimum height of stack, H required for an effective dispersion of particulates in air is given by

$H = 74 \, . \, Q^{0.27}$ Where Q is Particulate emission rate in tonnes per hour.

This often demands, stack heights in excess of 400 m especially in cement industries and thermal power plants and hence may prove uneconomical compared to particulate control by treatment.

Control at source:

The most effective means of dealing with the problem of air pollution is to prevent emission at the source itself. In the case of industrial pollutants, this can often be achieved by investigating various approaches at an early stage of process design and development, and selecting those methods which do not contribute to air pollution (or) have the minimum air pollution potential. It may be difficult to implement these methods in existing plants, but still some of the methods could be applied without upsetting the economy of the operation. Control of particulates at the source can be accomplished in several ways through raw material changes, operational changes, modification or replacement of process equipment and by more effective operation of existing equipment. Source locations through allocation of land usage i.e., proper planning and zoning of industrial areas is also one of the important means of control of pollutants. Some of the source correction methods are discussed briefly as follows.

Raw Material Changes:

Some raw materials are primarily responsible for causing air pollution. Use of pure grade of raw material is often beneficial and may reduce the formation of undesirable impurities and by-products or may even eliminate the troublesome effluents. Ore handling operations usually result in the emission of large quantities of dust into the atmosphere. In steel industry, replacement of raw ore with briquetted (or) pelletted sintered ore has greatly reduced dust emissions during ore handling and also helped to reduce the blast furnace 'slips' which result in emission to the atmosphere of enormous amounts of uncleaned blast furnace gas when the safety dampers open and allow the gases to byepass the dust collectors.

Process Changes:

Changing the process being used is still another important method of controlling emissions at their source. For example, petroleum/chemical industries have undergone radical changes in processing methods which emphasize continuous automatic operations, often computer controlled and completely enclosed systems that minimize the release of materials to the atmosphere. The volatile substances from storage tanks etc., are recovered by condensation and the non-condensable gases are recycled for additional reactions such as polymerization and alkylation of gaseous hydrocarbons to produce gasoline. Hydrogen sulphide, which was once flared in refineries, is now recycled and used in Clauss process to recover elemental sulphur.

Replacing open hearth furnaces with controlled basic oxygen furnaces or electric furnaces can reduce smoke, carbon monoxide and metal fumes while at the same time, conserving energy. Such changes, coupled with various combinations of gas cleaning devices, can be very effective in reducing air pollution.

In cement plants, rotary kilns are the major sources of dust generation. This can be reduced to some degree by adjusting operating conditions like reduction of the gas velocities within the kiln modification of the rate and location of feed, introduction and employment of a dense curtain of light weight chain at the discharge end of the kiln etc.

In the steel industry, a radically different process has been proposed to lower sulphurous emissions during combustion. In this process, the sulphur bearing fuel, limestone and air are injected into a molten bath. The combustibles in the fuel are partially oxidized to carbon monoxide within the molten iron bath, the gaseous CO comes off at the top of the molten iron and is burnt efficiently in a conventional manner. The sulphur is retained in the iron bath and forms a slag with the lime stone, which is removed.

Other examples involving process changes include:

1. Reduction of the formation of nitric oxides in combustion chambers by low excess air combustion in two stages, fuel gas recirculation and water injection.

2. Washing the coal before pulverization to reduce the fly ash emissions.

3. Substitution of bauxite flux for fluorine containing fluorspar in open hearth method.

4. The use of liquid and gaseous fertilizer chemicals like anhydrous ammonia, applied by injection into the earth instead of being spread across the surface as finely divided powders.

5. Reduction in oxidation of SC)2 to SOY by reducing excess air from 20% to less than 1% when burning fossil fuels, has eliminated sulfuric acid emissions. However, care should be taken as absence of excess air tends to result in greater soot production.

Equipment Modification (or) Replacement:

Another method of control of pollutants at the source involves the proper use of existing equipments, modification and replacement of equipments. For example, the un burnt carbon monoxide and hydrocarbons in the cylinders of an automobile engine, which are otherwise emitted into the atmosphere through the tail pipe, can be burnt by injecting air into the hot exhaust manifold of the engine. Similar results can be obtained by suitable modification in the carburetion and ignition systems.

Air pollutants emitted from industrial operations can be reduced by proper equipment maintenance, hand keeping, and cleanliness in the facilities and premises. Often, changes in the design of local exhaust hood and proper installation can minimize the emission of pollutants to the atmosphere. Chemical process plants often have excessive leakage around ducts, piping, valves and pumps. Many such leaks can be prevented by checking the seals and gaskets routinely Floors, decks, storage bins and silos, loading areas and material transfer conveyors must be kept clean to reduce dust pollution.

PARTICULATECONTROL BY USING EQUIPMENTS:

The most effective methods of particulate control are reduction at the source by the application of equipment and process control. If air pollution problems are properly considered in an industry prior to its design, real economy can be affected.

To remove the particulate matter from gas streams, various types of control equipment are available. But to select the required equipment, certain basic data must be available. The required data is:

1. Quantity of gas to be treated and its variation with time.
2. Nature and concentration of the particulate matter to be removed.
3. Temperature and pressure of the gas stream.
4. Nature of the gas phase (for solubility and corrosive effects).
5. Desired quality of the treated effluent i.e., efficiency of removal of particulates required.

Objectives of Using Control Equipment

1. Prevention of nuisance.
2. Prevention of physical damage to property.
3. Elimination of health hazards to plant personnel and general population.
4. Recovery of valuable waste products.
5. Minimization of economic losses through reduction of plant maintenance.
6. Improvement of product quality.

Particulate Control Equipment:

As pollutants, originating from a variety of sources primarily from industrial processes, airborne particulates exert a significant influence on atmospheric phenomena, plants, property and on animals including man. Control devices are divided into five major groups.

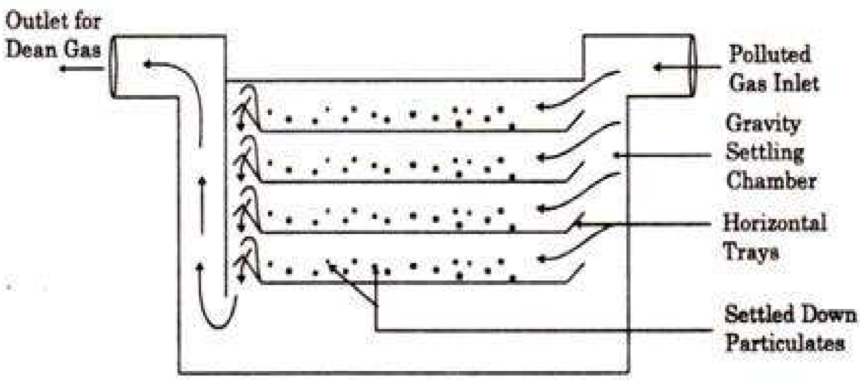
1. Gravitational settling chambers
2. Cyclones
3. Fabric filters
4. Electrostatic precipitators
5. Scrubbers (or) wet collectors.

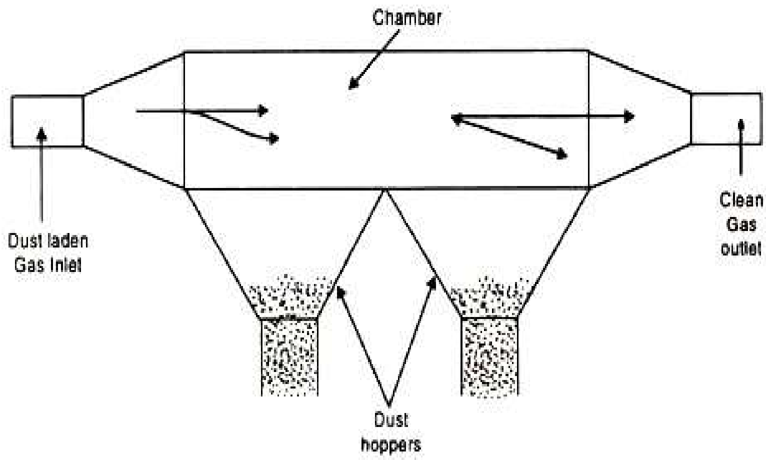
Each of these devices is uniquely suited to specific applications and the proper choice of method depends upon careful considerations of several factors, Particulate emission rates for different sources. Such particle characteristics as size distribution, shape, density, stickiness, hygroscopicity and electrical properties and such carrier gas properties as flow rate and particle concentration must be taken into consideration, such operational factors as continuous or intermittent emission, overall efficiency desired, available space, ultimate waste disposal methods required, and equipment limitations (i.e., pressure' temperature and corrosion) must be balanced against the economic considerations of installation operation and maintenance costs.

SETTLING CHAMBERS:

The gravitational settling chambers are perhaps the simplest and crudest of all pollution control devices. Settling chamber is almost the cheapest device to construct, operate and maintain and often serves as a preliminary screening device. Where the mass of larger particles is huge, the settling chamber can remove much of the mass of the particulate distribution which would otherwise choke up other control devices, impairing their operation or requiring frequent cleaning. Thus in majority of the particulate control devices, the first unit is a 'gravity settling chamber'. Gravitational force may be employed to remove particulates in settling chambers when the settling velocity is greater than about 0.12 m/s. Like settling tanks in water systems, gravity settling chambers are provided with enlarged areas to minimize horizontal velocities and allow time for the vertical velocity to carry the particle to the floor. The gravitational settling chambers usually operate with velocity between 0.5 and 2.5 m/s, although for best operating results the gas flow should be uniformly maintained at less than 0.3 m/s. Some settling chambers have simply enlarged conduits and some have horizontal shelves and baffles, spaced about 2.5 cm apart.

The collection efficiency of the chamber depends upon the type of flow also. For both laminar and turbulent flows, the design considerations are given in the following.





Design Considerations

Generally, settling chamber design based on laminar flow requires either a very large size or an inordinately large number of trays with an awkward shape of chamber. The laminar chamber has the advantage of giving theoretically perfect collection efficiency for particles of the designated size, but is of little practical value since the efficiency drops off rapidly with smaller particles. It is virtually impossible to collect very small particles with reasonably good efficiency using a settling chamber.

The most practical flow in the settling chamber will probably be turbulent rather than laminar. The turbulent chambers offer a more practical design concept, although no matter how big it may be, theoretically the chamber will never collect all particles of a specified size. The chamber should be reasonably designed for the removal of 99 percent of the particles which are as large or larger than some specified diameter, for example 50 or 100 µm. The turbulent settling chamber's design is also made by two assumptions:

First, there is a laminar layer adjacent to the bottom surface of the Passage into which turbulent eddies do not penetrate, because any particle which crosses into this layer will be captured shortly.

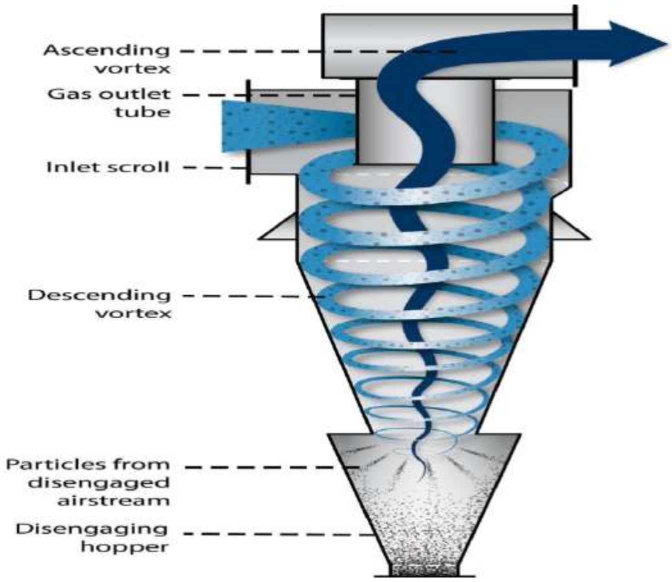
Second, in the remainder of the flow passage the eddying motion due to turbulence will cause a uniform distribution of particles of all sizes.

2. CYCLONES:

This class of separators is the most common of a general group of separators that are classified as centrifugal (or) inertial separators. It depends upon centrifugal force instead of gravity to separate particles from the gas stream. Because the centrifugal force generated can be several times greater than the gravitational force, particles that can be removed in centrifugal collectors are much smaller than those that can be removed in gravity settling chambers.

Reverse Flow Cyclones consist of a cylindrical shell, a conical base, dust hopper and an inlet where the dust gas enters tangentially. Under the influence of the centrifugal force generated by the spinning gas, the solid particles are thrown to the walls of the cyclone as the gas spirals upward at the inside of the cone. The particles slide down the walls of the cone and into the hopper. The operating (or) separating efficiency of cyclone depends on the magnitude of the centrifugal force exerted on the particles. The greater the centrifugal force, the greater the separating efficiency. Magnitude of the centrifugal force generated depends on particle mass, gas velocity within the cyclone and the cyclone diameter etc.

Cyclones are divided into two classes Conventional and High efficiency. High efficiency cyclones merely have a smaller body diameter to achieve greater separating forces.



Reverse Flow Cyclones

The efficiency ranges of cyclones are shown in table.

Particle size range (Microns)	Efficiency range % weight collected	
	Conventional	High efficiency
Less than 5	Less than 50	50-80
5-20	50-80	80-95
15-40	80-95	95-99
40 and above	95-99	95-99

In general, efficiency will increase with increase in dust particle size or density, gas inlet velocity, cyclone body or cone length and ratio of body diameter to gas outlet diameter and decreases with gas viscosity or density, cyclone diameter, gas outlet diameter and outlet velocity. Now a days, RFCs (Reverse Flow Cyclones) are mostly used in industrial operations for particulate control.

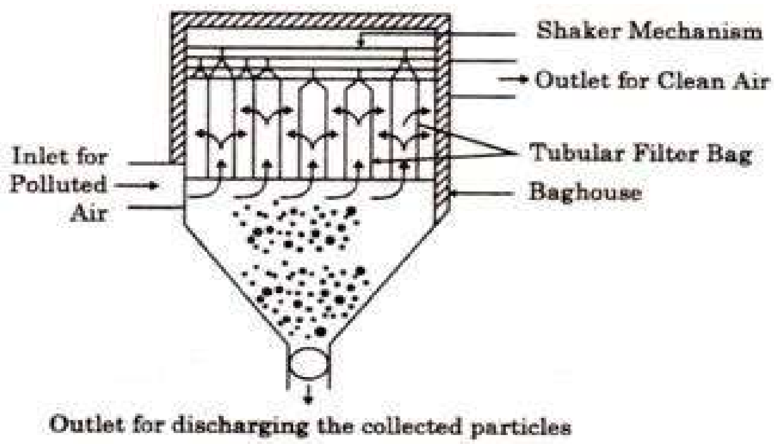
In straight flow cyclone, the inner vortex of the air leaves at the bottom with initial centrifugal motion being imparted by vanes at the top. The chief advantages of this unit are low pressure drop and high flow rates. In the impeller collector, gases enter normal to an impeller and are swept out by the impeller around its circumference while the particles are thrown into an annular slot around the periphery of the device. The main advantage of this unit is its compactness, but a drawback is plugging from solid buildup in the unit. For high efficiency at reasonable capacity, a battery of smaller cyclones operating in parallel is used in preference to a large unit that requires less space.

3. FABRIC FILTERS:

One of the oldest and most widely used methods of separating particulates from a carrier gas is 'Filtration'. A filter generally is a porous structure composed of granular or fibrous material which tends to retain the particulate and allows the gas to pass through the voids of the filter. The filter is constructed of any material compatible with the carrier gas and particulates and may be arranged in (I) fabric (or) cloth filters (2) fibrous (or) deep bed filters. Fibrous and deep bed filters have large void spaces amounting from 97 to 99% of the total volume. Fabric filters are made in the form of tubular bags or cloth envelopes and are suitable for a dust loading of the order of 1 g/m3. They are capable of removing dust particles as small as 0.5 microns and will remove substantial quantities of particles as small as 0.1 microns also. A bag house consists of 2 to 6 m long bags, the upper ends of which are closed and lower ends are attached to an inlet manifold. The hopper at the bottom serves as a collector for the dust. The gas entering through the inlet pipe strikes a baffle plate, which causes the larger particles to fall into a hopper due to gravity. The carrier gas then flows upward into the tubes and then outward through the fabric leaving the particulate matter as a "cake" on the inside of the bags.

The filter efficiency during pre-coat formation is low, but increases as the pre-coat (cake) is formed, until a final efficiency of over 99% is achieved. This pre-coat acts as a part of the filter medium, which helps in further removal of the particulates. Thus dust becomes the actual filtering medium. The bags, in effect, act primarily as a matrix to support the dust cake. The cake is usually formed in a matter of minutes or sometimes even seconds.

The accumulation of dust increases the air resistance of the filter and therefore filter bags have to be cleaned periodically. The cleaning can be done by rapping, shaking or vibration or by reverse air flow, causing the filter cake to be loosened and to fall into the hopper below. The gas is to be passed through the bags at a velocity of 0.4 to I m/min. Efficiency of bag filters may decrease on account of the factors like excessive filtration and selection of filter media. The ratio of the carrier gas volume to gross filter area per minute flow of gas is termed as 'filter ratio'. Excessive filter ratio will lower the particulate removal efficiency and results in increased bag wear.



Operational Problems

Operational problems associated with the use of fabric filters are:

1. **Cleaning**: After few hours of operation, the filters get so clogged up with a covering of due particles that the gas can no longer pass through them. Then the bags have to be cleaned by rapping, shaking, by reverse air flow or by pulse jet.
2. **Rupture of cloth:** While cleaning the filter (i.e., shaking), the greatest problem inherent in cloth filters is rupture of cloth. It is often difficult to locate ruptures and when they are found the replacement time is often considerable.
3. **Temperature:** Generally, the filters are designed for about 2500C to 3000C. The temperature related problem occurs whenever the effluent contains a reactive gas such as sulphur dioxide which can form an acid if the temperature in the bag house falls below the dew point. This can be prevented by having the bag house fairly well insulated. Sometimes, an auxiliary heater is used in winter season so that the temperature does not fall below the acid-gas dew point.
4. **Bleeding:** Bleeding is the penetration of fine particles through the filters. Bleeding occurs if the weave is too open or if the superficial filtration velocity (filter ratio) is too high. Generally, smaller particles only can penetrate through the fabrics and they only are responsible for primary human health hazard. The solution to bleeding problem is to use a double layer material of a thick woven fabric.
5. **Humidity:** Humidity control is a common and an important problem especially if a hygroscopic dust is involved. This problem can be overcome by taking suitable precautions.
6. **Chemical attack:** Another problem associated with fabric filters is the possibility of chemical attack due to corrosive chemicals such as $S0_2$ present in the process effluents.

Acid/Alkali Resistant filter cloths are to be used in such cases.

Filter cleaning:

Filter cleaning is one of the important operating problems in fabric filters. The filter leaning can be done by the following methods.

1. Shaking: The bags are joined to the shaker frame work by a rod and each shaker assembly consists of an electric motor, connecting arms and bearings. This method is not used for sticky dusts because the forces needed to remove the collected dust would probably cause tearing and rapping in the bags very quickly.

2. Reverse air flow (back wash): In this unit, the filter is cleaned by a high velocity air jet which is discharged from the inner side of a traversing ring that moves on the outside of the filter tube. The air jet passes through the fabric in a direction reverse to the normal flow and removes cake continuously from the filter surface.

3. Pulse jet: Here, a jet of high pressure air is blasted periodically down the inside of the bag which is supported by a wire frame. During the filter cleaning, the air jet inflates the bag momentarily When the bag is inflated the dust cake is loosened and falls into the hopper below. The two main advantages of this system are that there are no moving parts and continuous cleaning is possible. Also duration of the cleaning is insignificant compared to the length of filtering time between cleaning intervals. The pressure involved in operation is moderate to high. In general, while selecting the specific method of filter cleaning, we have to consider the cleaning mechanism, frequency and duration of cleaning and any undesirable effects on the bags.

Selection of Filter Medium:

While selecting the filter medium for bag houses, we must consider the characteristics and properties of the carrier gas and dust particles such as (i) carrier gas temperature (ii) carrier gas composition (iii) gas flow rate (iv) size and shape of dust particle and its concentration.

As far as the fabric is concerned, its abrasion resistance, chemical resistance, tensile strength and permeability should be considered. Of course, the cost of the fabric is also an important consideration. Apart from fabrics, a wide variety of filter cloths are available commercially. Cotton fabrics are used extensively where gas temperature is below 800C, and acid gases are absent. Wool fabrics are more resistant to acid than cotton and are used in the collection of metallurgical fumes and for fine and abrasive dusts such as cement. Other than this, many synthetic filter fabrics like nylons, polyesters are used in special applications.

Advantages of the Fabric Filters:

1. High collection efficiency for all particle sizes especially for particles smaller than 10 micron diameter
2. Simple construction and operation
3. Nominal power consumption
4. Dry disposal of collected material

Disadvantages

1. Operating limits are imposed by high carrier ga.4 temperatures, high humidity, etc
2. High maintenance and fabric replacement costs (replacing of leaking bag)
3. Larger size of equipment
4. Problems in handling dusts which may abrade, corrode or blind the cloths.

Application of Fabric Filters:

Fabric filters are extensively used in the following industries and operations:

1. Metallurgical industry
2. Foundries
3. Cement industry
4. Chalk and lime plants
5. Brick works
6. Ceramic industry
7. Flour mills etc.

4. Electrostatic Precipitators (ESP):

The electrostatic precipitators are particulate collection devices that utilize electrical energy directly to assist in the removal of the particulate matter. These are successfully used for removal of fine dusts from all kinds of waste gases with very high efficiency. The particles as small as a tenth of a micron also can be removed efficiently.

Electrostatic precipitator consists of six major components viz.

1. A source of high voltage
2. Discharge electrodes and collecting electrodes
3. Inlet and outlet for the gas
4. An electronic cleaning system
5. 'Hopper' for collection and disposal of particulates
6. An outer casing (called shell) to form an enclosure around the electrodes.

Principle of ESP:

Electrostatic precipitation is a physical process by which particles (solid or liquid) can be removed from the gaseous streams. The gas stream is passed between a pair of electrodes, across which high potential difference is maintained. The electrodes are discharge electrode at a high potential and an electrically grounded collecting electrode. Due to the high potential difference, a powerful ionizing field is formed. Under the action of electrical field, gas ions formed in the corona move rapidly towards the collecting electrode and transfer their charge to the particles by collision with them. The electrical field interacting with the charge on the particles then causes them to drift towards, and be deposited on the collecting electrode. The particles deposited on the collecting electrode lose their charge and then are removed mechanically by rapping or vibration to a hopper below the electrical treatment zone and are collected for ultimate disposal.

Types of Precipitators:

The main electrical mechanisms for precipitation of particles are (1) supplying an electrical charge to the particles for gas ionization and (2) supplying the electrostatic force that causes the charged Particles to drift towards the collecting electrode (for collection of particles).In the usual industrial electrostatic precipitators both these charges are supplied simultaneously and the precipitator acts as a single stage unit. In some cases like air conditioning applications and a few industrial applications a two stage precipitator is used in which two mechanisms are separated. Depending upon the electrode arrangements they may be classified as pipe type or plate type precipitators.

Pipe type precipitator: In the pipe-type precipitator, the nest of parallel pipes acts as the collecting electrode. The pipes may be of round, square or octagonal cross section. Generally the pipe is about 30 cm or less in diameter. The discharge electrode is a wire (2.8 mm dia) with a small curvature, suspended along the axis of each pipe. The wires are suspended from an insulated hanger at the top and kept under tension by weights attached to their lower ends and strong enough to withstand wrapping or vibrating for cleaning purposes. The pipe electrodes are 2 to 5 in height/length.

As the gas flows upwards, electrostatic forces cause the dust particles to migrate to the collector electrode where they stick. The cleaned gas then emerges at the top. The collected dust (aerosols) is removed periodically from the collector electrodes by rapping it; this dust then falls to the dust hopper.

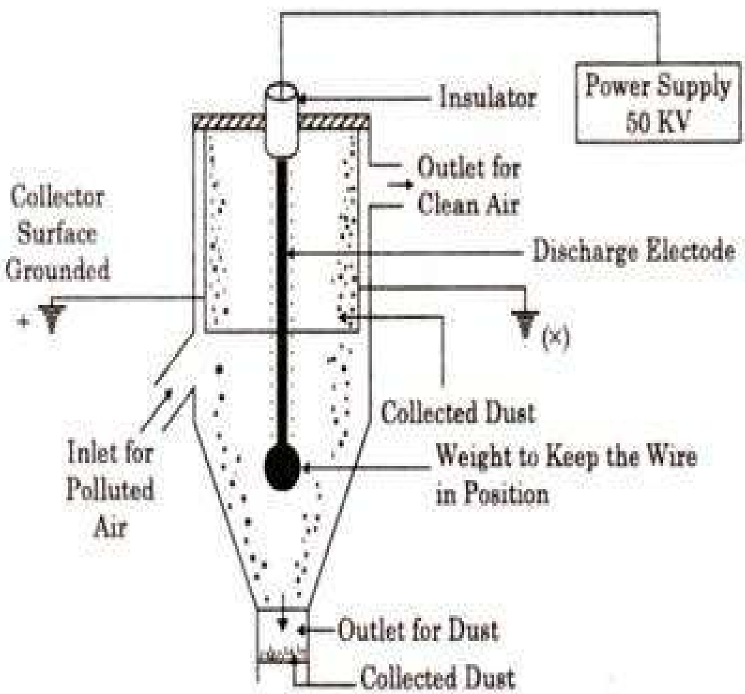
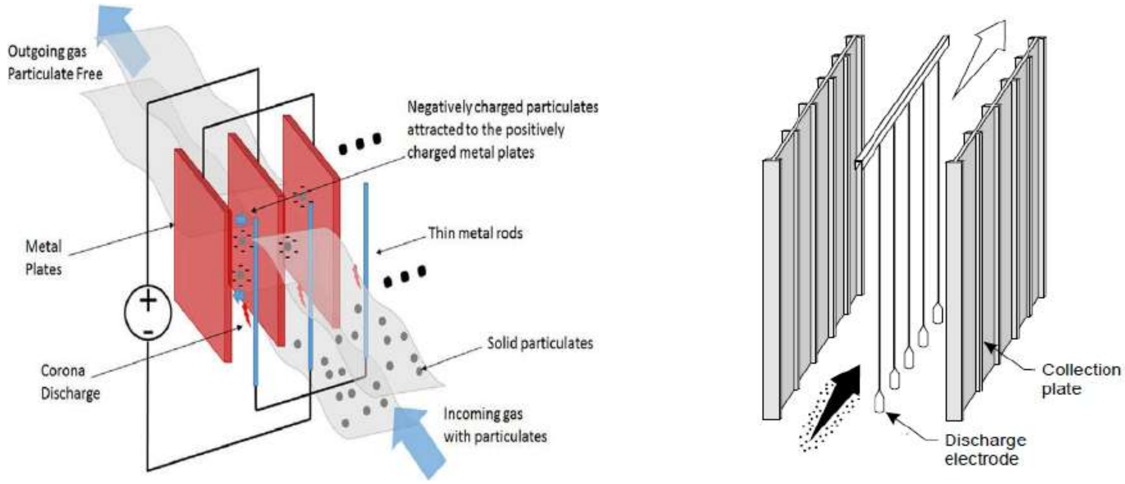


Plate type precipitator: In the plate-type precipitators, the collecting electrodes consist of parallel Plates of size 1—2 m wide and 3-6 m high. These parallel plates are spaced at 20—30 cm. The number of plates in the precipitators depends upon the inlet flow, so that the inlet gas velocities are 1-2 m/s in each channel. The discharge electrodes are similar to those used in pipe-type precipitator. Sometimes electrodes of square rods (4 to 5 mm) and twisted square rods (3.2 to 6.4 mm) are used. These discharge electrodes (i.e., wires), made from non-corrosive materials like tungsten, alloys of steel and Copper are suspended from the top and hang free with a weight attached at the bottom to keep them straight. The collection of the aerosols takes place on the inner sides of the parallel plates. The dust material collected can be removed by rapping and vibrating periodically.



The plate-type precipitators are generally employed for the collection of solid particulates. The collection efficiency of the precipitator depends upon the collection surface, bulking resistance and resistance to corrosion of the collection electrode.

Collection efficiency of the ESP:

$$\text{Efficiency} = 1 - \exp(-A_c V_p / Q)$$

V_P = particle migration velocity, m/sec

A_c = collector surface area, m^2

Q = Volumetric flow rate of the gas, m^3/sec

Advantages and Disadvantages of Electrostatic Precipitators:

Advantages:

1. High collection efficiency.
2. Particles as small as 0.1 micron can be removed.
3. Low maintenance and operating costs.
4. Satisfactory handling of large quantities of high temperature gas.
5. Treatment time is negligible (0.1 to 10 seconds).
6. Cleaning is easy by removing units of the precipitator from operation.
7. There is no limit to solid, liquid or corrosive chemical usage.

Disadvantages:

1. High initial cost.
2. Space requirement is more because of the large size of the equipment.
3. Possible explosion hazards during collection of combustible gases.
4. The poisonous gas, ozone is produced by the negatively charged discharge electrodes during gas ionization.

5. Precautions are necessary to maintain safety during operation.
6. Gases cannot be removed by ESPs.

Applications:

The important applications of electrostatic precipitators in industries are given in the following

1. Cement factories
2. Pulp and paper
3. Steel plants
4. Chemical industries
5. Petroleum industry
6. Carbon black industry
7. Thermal power plants

WET SCRUBBERS/WET COLLECTORS:

Nature uses 'wet scrubbing' as the method of cleaning herself since the world began. Rain or precipitation scrubs the air containing dusts and gases, as a result of which fresh-air sensation is experienced by one and all after a rain. Wet scrubbers are more universal in that they can function as either or both particulate and gas control devices. These particulate control devices utilize a liquid to assist in the removal of particulates from the carrier gas stream. In these devices water is the mostly used scrubbing liquid.

Wet scrubbers have the advantage of handling hot gases and sticky particulates and liquids. The disadvantages are that they require more operating energy and discharge wet gases and produce a wet product which results in problems like corrosion.

Huge quantities of water at the rate of 0.05—0.20 m3 of water per 100 m3 of gas are required, which in turn produce significant quantities of sludges.

Wet scrubbing method involves four major steps in collecting the particles. The stages are transportation, collision, adhesion and precipitation. In addition to removing entrained particulate matter, scrubbers can also remove gases by absorption and adsorption. This capability of scrubbers is not possessed by any other type of particulate control equipment. Scrubbers can remove particles of size 0.1 to 200 μm efficiently.

Collection Mechanism:

Particulates are removed from the gas stream mainly by absorption and adsorption.

Absorption by Impingement and Interception: When gas containing dust is swept through an area containing liquid droplets, dust particles will impinge upon the droplets, adhere and are finally collected by them. In general, the efficiency of collection is more when the liquid droplet is approximately 100 to 300 times the size of the dust particle, in order to increase the number of inelastic collisions.

Interception occurs when the particles have less inertia and almost follow the stream lines. Particles that move with the gas stream may not impinge on the droplets and adhere to them. This interception mechanism is predominant for particles of diameter above 0.3 μm.

Adsorption by Diffusion or Condensation: Diffusion of the dispersed onto the liquid medium helps in the removal of the particulate matter. This diffusion prevails for particles of diameter below 0.2 mm.

Similarly, condensation of the liquid medium vapours on the particulates increases the size and weight of particles, which exerts a force upon the particles and forces them to get deposited on the surface.

Types of Scrubbers:

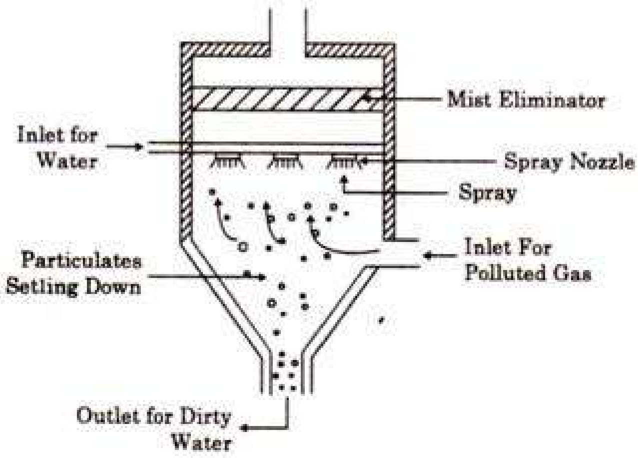
Presently, there are many scrubber designs available, where the contact between the Scrubbing liquid and the particles is achieved in a variety of ways. The common and important types of scrubbers are as follows:

1. Spray towers
2. Venturi scrubbers
3. Cyclone scrubbers
4. Packed scrubbers
5. Mechanical scrubbers

Spray Towers:

A spray tower is the simplest type of wet scrubber into which water is introduced by means of spray nozzles. It can be either round or rectangular, in which gas is passed,

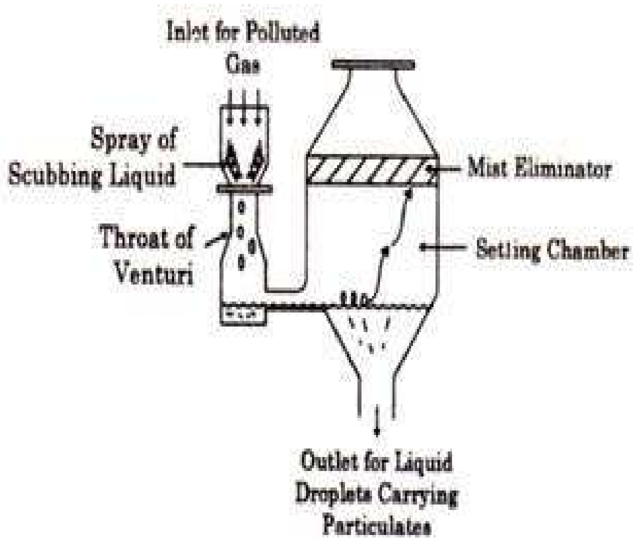
counter-current to falling drops of liquid (usually water) from spray nozzles. The particle collection can be done by the mechanism of inertial impaction and interception on the droplets. The towers are very effective in removing, particles in excess of 10 μm. The maximum efficiency occurs if droplets have a diameter of 800 μm (0.8 mm). The efficiency of a spray tower depends upon the droplet size, flow velocity of the gas, velocity of liquid etc. Spray tower effectiveness varies with the size of particles. It is 94 percent for 5 μm particles to 99 percent for 25 μm particles.



Venturi Scrubbers:

Venturi scrubbers are high energy wet scrubbers with high performance collection of fine particles, usually smaller than 0.5 to 5 µm diameter, They are particularly suitable
for submicron particulates associated with smoke, fume and also highly corrosive matter. Venturi scrubbers may have converging and diverging sections but usually the angles are greater to keep down the length. The high performance of the venturi scrubber is achieved by accelerating the gas stream to very high velocities, of the order of 60—180 m/s. Due to the high speed action, the feed liquid is atomized with a uniform fashion across the throat through several low pressure spray nozzles directed radially inward .

The droplets accelerate in the throat section and due to the velocity difference between the particles and the droplets the particles are impacted against the slow moving droplets. The acceleration continues to •some extent into the diverging section of the venturi. The gas liquid mixture is then directed to a separation device such as a cyclone separator where particulate matter is separated from the gas stream. The affecting mechanisms for collection of particulates in the scrubber are inertial impaction, diffusion, electrostatic phenomenon and condensation and agglomeration. But the principal mechanism is inertial impaction. The application of venturi scrubber is used in kraft mill furnaces, metallurgical furnaces, sulphuric acid concentrators etc., for removing mists and dusts from gases.



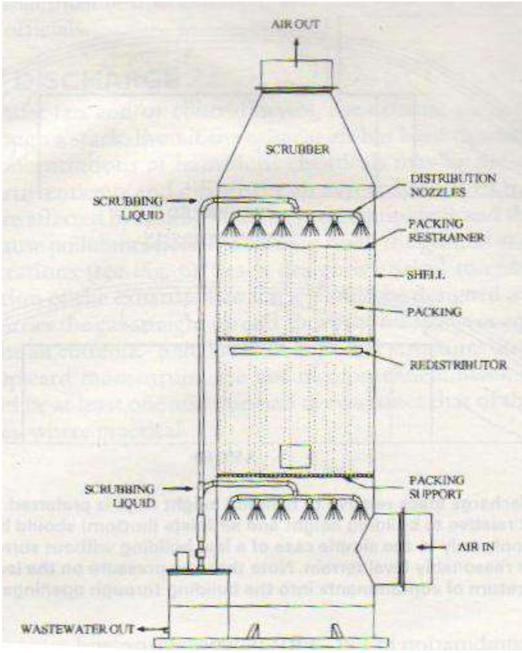
Cyclone Scrubbers:

It is the modification of the dry cyclone by the addition of liquid phase.

In cyclone scrubbers, the gas is tangentially swirled around, same as in dry cyclone. Water sprays from the top of cyclone and outside the wall. In cyclone scrubbers inertial impaction and separation are the main collection mechanisms. For droplets of 100 µm, efficiency approaches 100% and 90 to 98 percent removal is achieved for droplets between 5 and 50 µm. Generally, efficiencies slightly higher than those obtained with the spray tower or the dry cyclone can be expected.

Packed Scrubber:

In packed scrubber, fibre glass (fine glass filaments) or other packing (coke or broken stone) are used as the collection material. The polluted gas stream moves upward in a counter current-flow packed scrubber and comes in contact with the scrubbing liquid stream which is moving downward over the packing in a film. The gas stream passes through the packing pore spaces and captures the particles by the inertial impaction. Because of the good mass transfer characteristics of the packing, efficient collection of fine particles by diffusion is also possible. Smaller packing increases the efficiency of collection but its shape does not appear to affect the collection efficiency. Sometimes packing towers encounter plugging problems, which can be reduced by employing sprays to wash the packing or by using low density spheres etc. Recently a moist chemical foam packing has been employed, which drains slowly from the scrubber with captured particles and is replaced with fresh material.



Mechanical Scrubbers:

Mechanical scrubber is the high energy scrubber, and has mechanical means of breaking up the scrubbing liquid into small droplets and simultaneously creating turbulence. It has internal rotating mechanical part, where the liquid dispersoid contact is achieved by
the simultaneous introduction of the liquid medium and the gas stream. The scrubbing liquid dribbles down on the rotating part and is struck violently and disintegrated into fine droplets that are thrown radially by the centrifugal force and are removed quite easily. These scrubbers have a high initial cost, high operating cost and require considerable maintenance. The quantities of water required and wasted also are very high.

Advantages of Wet Collectors:

1. Wet scrubbers have an additional advantage if some gases and particulates are to be removed simultaneously. For example, if $S0_2$ or NH_3 are the gases to be removed then,

$$SO_2 + H_2O \rightarrow H_2SO_3 / H_2SO_4$$

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

H_2SO_4 and ammonium sulphate, $(NH_4)_2SO_4$ are valuable by products.

2. High removal efficiencies even for submicron sized particulates.

Disadvantages of Wet Collectors:

1. High pressure losses and high operational costs.
2. Quantity of sludge developed is very high. Handling of such huge quantities of sludge is very difficult and costly.

The sources of air pollution are human activities connected to mobility, power generation, space conditioning/HVACR (Heating, Ventilation, Air Conditioning, and Refrigeration) and manufacturing. These activities in turn are the defining features of modern 'civilised' life. As human beings across all countries aspire for a higher standard of living, these activities will continue to multiply in the future. It is interesting to note that all these activities are based on energy conversion. While all life forms on earth depend on the Sun for their energy, human beings have particularly exploited the reserves of energy stored under the earth's crust. These are available in solid, liquid and gaseous forms and are collectively called fossil fuels. Sun's energy has been stored by plants, the primary producers. The plant material which has been buried under the earth's crust over millennia have stored this sun's energy in coal, oil and gas forms which are extracted by various means for further human use.

Therefore, the problems of air pollution originate in the conversion of energy stored in these fossil fuels to some useful work. In Engineering, we use different approaches to control pollution depending on the economics and the government regulations. Those practises which try to remove the cause of pollution are called process changes while those which remove the effects are termed as 'end of pipe' solutions. In the remaining units of this course, we look at both process changes and 'end of pipe' solutions for air pollution problems. Even though it takes longer to create a 'process change', the outcomes are beneficial for longer period of time compared to 'end of pipe' solutions which are short lived. Before we enter into specific process changes and 'end of pipe' solutions for control of air pollution, we need to understand how polluting gases and particulates are formed and think of ways to alter them.

Thermodynamics is the branch of physical science that deals with the relations between heat and other forms of energy (such as mechanical, electrical, or chemical energy), and, by extension, of the relationships between all forms of energy.

Kinetics is the branch of chemical science concerned with measuring and studying the rates of reactions.

These disciplines are essential to designing both process changes and end-of-pipe solutions. In this unit, we look at the basics of combustion, how it happens in open air and how it might happen in industrial environments. The principles of Thermodynamics and Kinetic give us an insight into how we might design better processes and end of pipe solutions to control air pollution. The solution that saves energy also reduces pollution as less fuel is burnt for the same amount of work done or product manufactured.

Considering the air pollution phenomena that are witnessed across the world such as global warming, acid rains, heat island effect and ozone holes, we shall look at the formation of the most important gases that are responsible for these effects namely, CO, SO_x, NO_x in various industrial conditions.

Thermodynamics of formation of Carbon Monoxide:

Carbon Monoxide is a toxic gas that can kill people if consistently inhaled over a period of time. It is 200 times more active in combining with the haemoglobin in our blood. Thus the haemoglobin that combines with CO to form Carboxy-Haemoglobin is unable to carry oxygen to various tissues in our body. When starved of Oxygen, the cellular metabolism slows down and ultimately cells die leading to the loss of consciousness and death unless CO is replaced by plenty of oxygen.

Carbon Monoxide does not occur in significant proportions in ambient air. It is usually formed when Carbon does not have enough Oxygen in the burning process.

CO is formed as an intermediate product of the combustion reaction between carbonaceous fuels and oxygen rich mixture that is insufficient quantities of oxygen lead to the formation of CO as the final product. Lean mixtures (excess oxygen) also may form CO due to either poor mixing of fuel and air or dissociation of CO_2 to CO due to the high temperature regions of the combustion zone. The CO_2 - CO equilibrium is shown in the following table.

Equilibrium constants for CO - CO_2 oxidation

	K	
	298	$1.2 X 10^{45}$
	500	$1.1 X 10^{25}$
	1000	$1.7 X 10^{10}$
	1500	$2.1X 10^{5}$
	2000	766
	2500	28
	4000	0.2

Thus it can be observed that if the temperature is no more than 2000°K, value of K_p will be very less, indicating that CO_2 dissociation to CO is significant. Hence rich mixtures, poor mixing of air & fuel and high temperatures may lead to significant formation of CO, especially in the hot combustion zones. This can be clearly observed in the following table.

Distribution of CO, CO_2 and O_2 with temperature

C/O Ratio	K	**XCO**	**XCO_2**	**XO_2**
1/3.12	298	traces	0.637	0.362
1/3.12	1000	0.001	0.637	0.362
1/3.12	2000	0.003	0.635	0.363
1/3.12	*3000*	*0.198*	*0.378*	*0.425*
1/3.12	4000	0.437	0.063	0.501
1/2	*3000*	*0.363*	*0.454*	*0.182*
1/5	*3000*	*0.113*	*0.264*	*0.623*

Thus all the combustion processes should operate at excess air conditions to avoid the formation of CO.

Thermodynamics of formation of Sulphur Oxides:

Coal contains 0.5 to 4 % of Sulphur. If it contains less than 0.5% Sulphur, it may be considered as a very low Sulphur coal. Residual fuel oils also contain 1- 4% Sulphur. Thus all the fossil fired combustion processes release significant quantities of oxides of sulphur. The overall reaction for the formation of Sulphur dioxide from Sulphur in fossil fuels is :

The reaction is highly exothermic with a heat release of about 300,000 kJ/Mole at 25°C. In addition to SO_2, traces of SO_3 also are formed in the combustion reaction. In the combustion of fossil fuels, the is typically 40:1 to 80:1

SO_2 can act both as a reducing and oxidising agent at normal atmospheric conditions. For eg.

Where SO_2 acts as an oxidising agent. Other thermodynamic reactions of importance are

Here particulate matter and NO_x act as the catalysts.

In the presence of humidity, SO_x forms acid mists as below

Metal salts such as Sulphates and Chlorides of Iron and Manganese are the noted catalysts for these reactions. The acid mists are corrosive and reduce visibility and are responsible for the formation of acid rains. The thermodynamic equilibrium relationship between SO_2 and SO_3 is given by the table below.

Equilibrium constants for SO_2 - SO_3 reaction.

	K	
	298	$2.6 X 10^{12}$
	500	$2.6 X 10^{5}$
	1,000	1.8
	1,500	$3.8 X 10^{-2}$
	2,000	$5.6 X 10^{-3}$

From the values of K_p it can be observed that SO_3 formation is favoured only at low temperatures and that is very high at higher temperatures. Thus SO_3 concentrations are very small in the actual flame zone and very large in the cooled flue gasses. However, the concentrations of SO_3 in power plant furnace, were observed to be altogether different. The anomalous behaviour of SO_3 is due to the role of Kinetics in determining the rate of formation of intermediate products like SO and SO_2. The equilibrium reaction of SO with Oxygen to form SO_2 is thought to be the reason for the deviation in measurement of SO_3 concentration in flue gases. The main concern with reference to impact of air pollution on man and material, is the removal of SO_3. The major SO_3 removal processes are

In the hot reaction zone, where high levels of O atoms occur, it is quite reasonable to assume that SO_3 concentrations are less. But practically it was observed that the SO_3 concentration is about 1 - 5% of the SO_2 concentration. The SO_3 concentration is further suppressed under fuel-rich conditions. Thus it may be concluded that SO_2 is the main oxide of Sulphur formed in combustion and that the conversion of SO_2 to SO_3 in the atmosphere is a slow process. However, SO_2 is converted to SO_3 easily in the presence of particulates and humidity. This leads to an increase in Sulphate aerosol formation that is dangerous to man and materials.

Thermodynamics of formation of Nitrogen Oxides:

The main sources of NO_x emission are 1. Nitrogen present in the fuel itself and 2. Nitrogen present in air used for combustion. If excess air is not used, CO, HC and other undesirable intermediate air pollutants may be formed. If excess air is used to control their emission, NO_x emissions increase as surplus oxygen combines with Nitrogen. The two main reactions of concern in air pollution are

NO_2 emissions can be reduced by reducing the peak combustion temperature and by reducing excess air available for combustion.

Thermodynamics of combustion:

Combustion is the main process responsible for both generating air pollution and controlling air pollution. For example odours generated through combustion processes are controlled mainly by destruction which is again achieved by combustion only. Combustion is an exothermic reaction in which thermal energy is released when the reaction occurs. Some of the common combustion reactions are

Thus oxygen is the main element required for combustion. Normally air is supplied to the fuel to supplement the oxygen requirement instead of supplying pure oxygen for combustion. Air contains about 21% of Oxygen and 79% of Nitrogen by volume and hence for every 1 mole of Oxygen present in air, there will be 3.76 moles of Nitrogen. Thus the actual combustion equations may be written as

These equations are the theoretical stoichiometric equations of combustion which represent complete combustion of fuel which can be achieved only if every fuel molecule mates perfectly with every oxygen molecule. Such a condition requires an infinite time at very high temperature and perfect mixing. Thus the three 'T's that are very essential for an efficient combustion are

T - Temperature

T - Time

T - Turbulence

Practically it is not possible to allow perfect mixing to take place. Hence excess air that is air that is more than theoretical or stoichiometric air is supplied to enable complete combustion to take place. For eg., in 20% excess air, the actual combustion reactions would be

If excess air is not employed, every oxygen molecule may not come in contact with every molecule of fuel resulting in the formation of some undesirable intermediate products. This incomplete combustion may be exemplified by

If the oxygen (or air) availability is considerably less than the theoretical requirement, there may be some hydrocarbons also in the products of combustion. ***The excess air to be provided is a function of the fuel characteristics, combustion temperature and the turbulence or mixing provided.*** For e.g. even a 10% excess air produces the undesirable intermediate product of CO, as follows if mixing is not proper.

$+ 0.225$

The amount of Oxygen or Air provided for combustion is mostly represented by a parameter called AFR (Air Fuel Ratio).

AIR FUEL RATIO

The ratio of mass of air to the mass of fuel is called air fuel ratio AFR and is given by

$$AFR = M_a N_a / M_f N_f \text{ where}$$

M_a = Molecular Weight of air (21% O_2 + 79% N_2) = 0.21 X 32 + 0.79 X 28 = 28.97

N_a = Number of moles o air = Number of moles of O_2 + Number of moles of N_2

M_f = Molecular weight of fuel

N_f = Number of moles of fuel

Mixture strength which is the ratio of stoichiometric AFR to the actual AFR, is most significant parameter that governs the products of combustion. Higher mixture strengths (>100%) cause incomplete combustion and hence undesirable products such as CO are formed.

Usually boilers operate at about 20% weak mixtures. Gas turbines at 300% weak mixtures whereas there is a wide variation in the operation of petrol engines. If excess air is more, Nitrogen reacts with the excess Oxygen forming NO_x emissions. Hence optimum mixture strengths must be provided to minimise emissions of air pollutants.

Combustion of Fuels:

There are two large reservoirs of organic material from which simple carbonic compounds can be obtained - Petroleum and Coal, and are known as fossil fuels. Being the products of the decay of plants and animals, these simple organic compounds are used as the building blocks from which larger and more complicated compounds are made. These fossil fuels, particularly petroleum are being consumed at an alarming rate to meet man's greedy demands for power. 90% of petroleum is simply burnt to supply energy and only 10% is used in making chemicals. The only alternative to these conventional fuels may be the origin of the fossil fuels itself, the biomass, which is renewable and can last for millennia if used properly.

Carbon atoms attach themselves to one another to an extent not possible for other atoms. They can form chains thousands of atoms long or rings of all sizes; the chains and rings can have branches and cross-links. To these are attached other atoms mainly hydrogen but also Fluorine, Chlorine, Bromine, Iodine, Oxygen, Nitrogen, Sulphur, Phosphorus etc., Each different arrangement of atoms corresponds to a different compound and each compound has its own characteristic set of physical and chemical properties. Nearly 1 crore compounds of carbon are known today and this number is increasing 5 lakhs a year. The most significant fuels and their potential for air pollution problems are described as follows.

COMBUSTION OF COAL:

Coal is the most readily available energy source. Technologies to produce clean gas and liquid fuels from coal may spur increased use of this energy source. It is predicted to be sufficient for the next 600 years. It is extensively used in spite of this two limitations- (i) Comparatively it is difficult to handle and use especially in smaller installations (ii) When burned it releases uncontrolled air pollution emissions.

A variety of coals are available, all over the world. 'As received' analysis of a typical bituminous coal sample could be 3.0% moisture; 21% volatile matter; 70% fixed carbon and 6.0% ash. It has a heat value of about 7330 cal/gram. However, the ultimate analysis for this sample is 79.90% Carbon; 4.85% Hydrogen; 0.69% Sulphur; 1.30% Nitrogen; 6.50% ash and 6.76% Oxygen. It has a true specific gravity of 1.40-1.70 for Anthracite and 1.25-1.45 for Bituminous. The specific gravity of loose-packed coal is about 0.64.

When coal is heated, volatile matter is produced. After heating the fixed carbon and ash remain. Fixed carbon can be burned off leaving the ash. The non-combustible mineral matter in coal produces the bottom ash and some of the fly ash particulates. Coal contains both inherent and extraneous mineral matters. The inherent matter, originated as a part of the growing plant life that produced the coal is uniformly distributed and makes up about 3% of the coal. Extraneous mineral matter is the inorganic material originated from the strata surrounding the coal seam.

During combustion of mineral matter becomes hard or melts forming the ash. The quality of ash produced depends on the furnace conditions and composition of coal. Another unwanted element present in coal is Sulphur. It is available in 3 forms - Pyrites, Organic or Sulphates. About 50% of sulphur is constituted by Pyrites or Iron sulphide. Organic Sulphur consists of complex organic molecules. Sulphates are present to a small extent and are present only in fresh coal. Coal washing processes can remove more than 50% of pyrites and mineral matters. Coal also contains significant concentrations of Boron, Cadmium and Selenium. Coal is basically burned as fuel placed in a bed, in suspension or in an fluidised state . The fluidised bed combustion of coal is gaining significance as it produces less NO_x and reduces volatilisation of Sodium and Potassium from the ash. With this high heat transfer rates and large combustion efficiencies are possible. In addition, High SO_2 removal also can be obtained.

The main air pollutants from the combustion of coal includes particulates, SO_x ,CO, HC, NO_x and aldehydes. The concentration of these pollutants depends on the type of coal, combustion process and the operational characteristics such as temperature, turbulence, mixing, excess air etc., the particulates consists mostly of ash particles and the unburned coal blown during the turbulent combustion.

More than 95% of sulphur present in the fuel is converted into SO_2. Presence of rare metal such as platinum and vanadium present in the ash can catalyse the conversion of SO_2 to SO_3. Presence of excess air further increases the formation of SO_3. In the presence of water vapour, SO_3 forms acid mists, which are highly dangerous.

NO_X is produced if the combustion temperature is high. The two basic sources of nitrogen are

(i) Nitrogen present in the fuel itself and (ii) Nitrogen present in the air used for the combustion. Excess air increases NO_X concentrations. Large coal-fired boilers emit more NO_X than any other combustion source. If excess air is more NO_X concentrations are more but the concentration of CO and hydrocarbons will be very low. Thus an optimum excess air must be maintained to control the air pollutants. Coal combustion emission may also include materials such as Arsenic, Beryllium, Lead, Mercury and radioactive materials.

COMBUSTION OF OIL:

Oil is the most versatile energy source. It is easy to transport, burns relatively clear, is safe to use and has a high energy to volume ratio. Natural fuel oils are obtained from crude oils. The typical composition of a diesel oil is 0.2% sulphur, 13% Hydrogen, 87% Carbon, <0.1% Nitrogen and 0.01% Ash. It has a specific gravity of 0.84 and has heating value of 11.19 kcal/gram. Kerosene has more or less the same properties. However it has sulphur content of less than 0.05%. Kerosene has a molecular formula of $C_{12}H_{26}$.

For combustion of oil, they must first be atomised by oil burners to produce drops of sizes less than 50μ diameter. Oil is then sprayed into the boilers to mix with combustion air. Oil burners usually operate at 5-10% excess air.

Properly operated oil burners produce less air pollution compared to coal combustion. Horizontal and tangential firings are the two basic arrangements in firing. The oil is directed towards the centre of the furnace in a horizontal firing system resulting in a hotter flame and hence the formation of NO_x. Similarly, large boilers burn hotter hence produce more NO_x than smaller ones. In an oil fired boiler about only 0.65% of SO_2 is converted to SO_3.

COMBUSTION OF GAS:

Gases are the cleanest burning fuels and hence are the best suited for the minimum air pollution generation. Of all gases, natural gas is the most available fuel. It has a significantly high gross heating value of 8900-9800 kcal/Nm^3. It has a relative density of about 0.57, when referred to air. Artificial gas, also known as manufactured gas or city of gas is a mixture of water gas, coal gas and others. Carburetted gas, Producer Gas and Coke Oven gases are made from coal or coke. LPG, the liquefied petroleum gas is a gasoline refining by product and consists mainly of Butane an d Propane and traces of Butylene and Propylene. Although it is distributed as a liquid under pressure, it reverts to gaseous state before burning. LPG commonly known as bottled gas has a heating value of 6000 - 6400 Kcal/Nm^3. Different fuels have different applications. Gasoline (petrol) is used in internal combustion engines that require a fairly volatile fuel. Kerosene is used in tractor and jet engines and gas oil is used in diesel engines. During the combustion of gaseous fuels, both gaseous fuels and air are forced together through nozzles and the flame is sustained. The residence time near the tip of burner is about 0.25 to 3 seconds, depending upon whether the temperature is high or low. Gas burners typically operate at 3-15% excess air. As majority of gaseous fuels contain only traces of Sulphur, the SO_x emissions resulting from the combustion of gases is almost negligible. As gases can easily mix with air, minimum excess air is sufficient for an efficient combustion.

Thus gases can be burnt with minimum NO_x emissions.

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UNIT – IV

SOLID WASTE GENERATION AND COLLECTION

Syllabus:

Introduction:

Characteristics-types, sources and properties of solid waste, Generation, typical generation rates, Estimation of solid waste quantities, Factors that affect generation of wastes- collection services, Types of collection systems, Determination of vehicle and labour requirement, Transportation of solid waste- transfer stations, Transfer means and methods.

Learning Outcomes:

Student will be able to

- Identify the types and sources of solid waste and its characteristics
- Employ the treatment and disposal methods of solid waste.
- Apply the concepts of solid waste management.

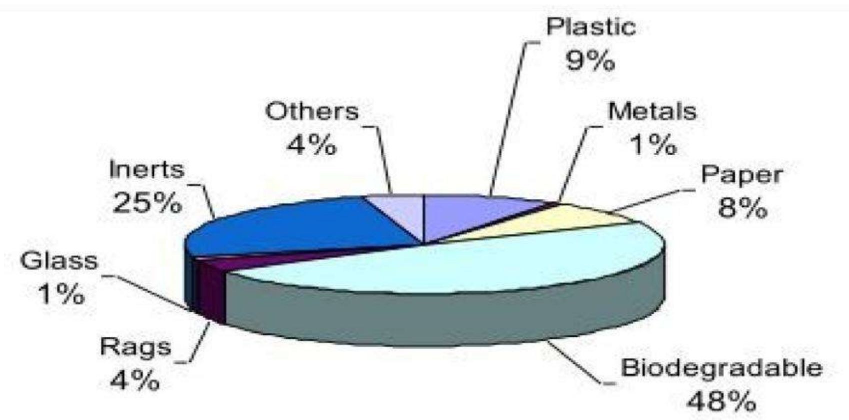
DEFINITION:

"**Solid wastes are all the wastes arising from human and animal activities that are normally solid and that are discarded as useless or unwanted"**

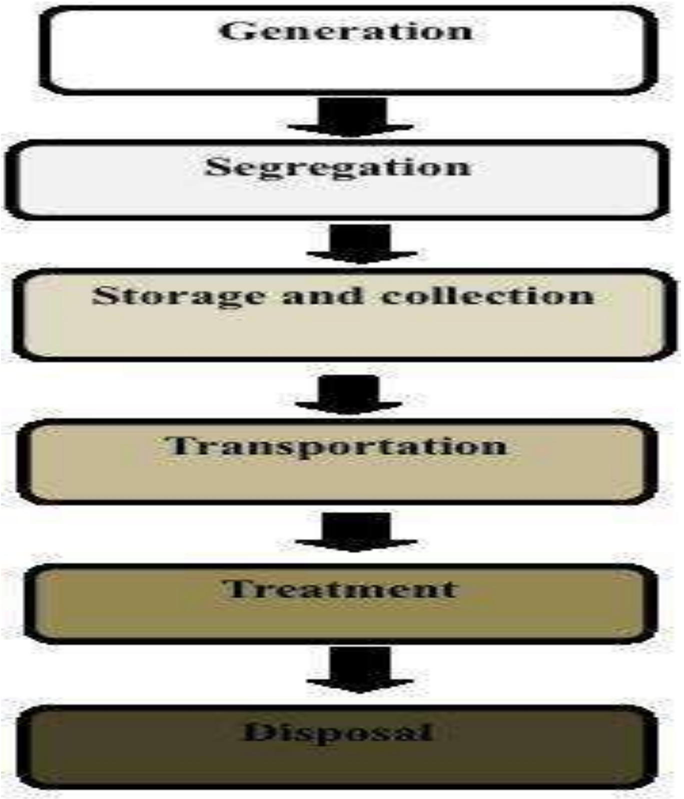
Solid waste may consist of organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries.

COMPOSITION OF SOLID WASTE IN INDIA

The composition of municipal waste varies greatly from country to country and changes significantly with time.



LIFE CYCLE OF SOLID WASTE



CLASSIFICATION OF SOLID WASTES

Solid wastes are the organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc., produced in a society. Solid wastes, thus, encompass both a heterogeneous mass of wastes from the urban community as well as a more homogeneous accumulation of agricultural, industrial and mineral wastes. While wastes have little or no value in one setting or to the one who wants to dispose them, the discharged wastes may gain significant value in another setting.

Source-based classification

Historically, the sources of solid wastes have been consistent, dependent on sectors and activities and these include the following

(i) **Residential:** This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.

(ii) **Residential:** This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.

(iii) **Commercial:** This refers to wastes consisting of leftover food, glasses, metals, ashes, etc., generated from stores, restaurants, markets, hotels, motels, auto-repair shops, medical facilities, etc.

(iv) **Municipal:** This includes dust, leafy matter, building debris, treatment plant residual sludge, etc., generated from various municipal activities like construction and demolition, street cleaning, landscaping, etc.

(v) **Industrial:** This mainly consists of process wastes, ashes, demolition and construction wastes**,** hazardous wastes, etc., due to industrial activities.

(vi) **Agricultural:** This mainly consists of spoiled food grains and vegetables, agricultural remains, litter, etc., generated from fields, orchards, vineyards, farms, etc.

(vii) **Open areas**: this includes wastes from areas such as Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.

Type-based classification

Classification of wastes based on types, i.e., physical, chemical, and biological characteristics of wastes, is as follows

Food waste:

Animal, fruit or vegetable residues resulting from handling, preparation, cooking and eating of foods also called as garbage, highly putrescible and will decompose rapidly, especially in warm weather leading to offensive odour

Rubbish:

Consists of combustible and non-combustible solid wastes of households, institutions, commercial activities excluding food waste. Typically combustible materials consists of paper, cardboard, plastics, leather, wood, furniture.

Non-combustible consists of glass, crockery, tin cans, dirt, ferrous & non-ferrous materials.

Ashes & Residues:

Materials remaining from the burning of wood, coal and other combustible wastes in home, stores, institutions and industrial facilities for purpose of heating, cooking and disposing.

Composed of fine, powdery materials, clinkers, and small amounts of burned and partially burned materials.

Glass, crockery and various metals are also found in residues from municipal incinerators.

Construction and Demolition wastes: Wastes from demolished buildings and other structures. Wastes from construction, repairing of individual residencies, commercial buildings. It includes dirt, stones, concrete, bricks, plumbing, heating and electrical parts.

Special Waste:

Wastes such as street sweepings, roadside litter, dead animals, abandoned vehicles. Because it is impossible to predict where dead animals and abandoned vehicles will be found, these wastes are often identified as originating from non-specific sources.

Treatment plant wastes:

Solid and semi-solid wastes from water, waste water and industrial waste treatment facilities.

Special characteristics of these materials vary depending on the nature of treatment process.

Agricultural Waste:

Wastes and residues resulting from diverse agricultural activities such as planting and harvesting of fields, crops, operation of feedlots.

Hazardous wastes:

Chemical, biological, flammable, explosive or radioactive wastes that pose a substantial danger, immediately or over time, to human, plant or animal life.

Wastes occurs as liquids, but often found in form of gases, solids or sludges.

Characterization of Plastics:

There are mainly two types of plastics namely commodity plastics and special plastics. The characteristics of commonly plastics are polyethylene (PE), polypropylene (PP), polystyrene (PS), poly vinyl chloride (PVC) and poly eyhylene teraphthalate (PET) which are around 80%. The special plastics are engineered and specialty plastics characterized as acrylonitrile butadiene styrene (ABS), styrene acrylonitrile (SAN), Polyamide plastic pipe (PA), poly butalene teraphthalate polyester (PBT), polycarbonate plastic (PC) and polyurethane (PU) which are around 20%.

(i) Bio-Medical Waste

Bio-medical waste means any waste, which is generated during the diagnosis, treatment or immunization of human beings or animals or in research activities. Pertaining thereto or in the production or testing of biological and including human anatomical waste (Body parts, body organs, Blood bags and blood preserves) animal waste, microbiology and bio-technology waste, waste sharps, discarded medicines and cytotoxic drugs, soiled waste, solid waste, incineration ash and chemical waste.

Table 1 Biodegradable and Non-Biodegradable Wastes:

Degeneration Time

category	Type of wastes	Time taken to de generate
Biodegradable	Organic waste such as vegetable and fruit peels, leftover foodstuff, etc.,	A week or two weeks
	Paper	10-30 days
	Cotton cloth	2-5 months
	Woolen items	1 year
	Wood	10-15 years
Non-Biodegradable	Tins, aluminum, and other metal items	100-500 years
	Plastic bags	One million years
	Glass bottles	Un determined

Characteristics of solid waste:

1. **Physical Characteristics**

Density

Knowledge of the density of a waste i.e. its mass per unit volume (kg/m^3) is essential for the design of all elements of the solid waste management system viz. Community storage, transportation and disposal. For example, in high-income countries, considerable benefit is derived through the use of compaction vehicles on collection routes, because the waste is typically of low density. The situation in low-income countries is quite different: a high initial density of waste precludes the achievement of high compaction ratio. Consequently, compaction vehicles offer little or no advantage and are not cost-effective.

Significant changes in density occur spontaneously as the waste moves from source to disposal, as a result of scavenging, handling, wetting and drying by the weather, vibration in the collection vehicles. Density is as critical in the design of a sanitary landfill as it is for the storage, collection and transportation of waste. Efficient operation of a land fill requires compaction of the waste to optimum density after it is placed.

Density of Municipal Solid Wastes in Some Cities

Sl. No	City	Density (Kg/m^3)
1.	Bangalore	390
2.	Baroda	457

3.	Delhi	422
4.	Hyderabad	369
5.	Jaipur	537
6.	Jabalpur	395
7.	Raipur	405

Bulk Density Measurement

Materials and apparatus:

- Wooden box of l m^3 capacity
- Wooden box of 0.028 m^3 capacity
- Spring balance weighing up to 50 kg.

Procedure: The solid waste should be taken in the smaller 0.028 m3 box to give a composite sample, from different parts of the heap of waste, and then weighed with the help of a spring balance. After weighing, this smaller box (0.028 m3) is emptied in bigger l m3 box and the weight of the waste poured into the bigger box is noted. This is repeated till the larger box is filled to the top. The waste should not be compacted by pressure. Fill the l m3 box three times and take the average. Thus the weight per cubic meter is obtained.

Moisture Content:

Moisture content of solid wastes is usually expressed as the weight of moisture per unit weight of wet material.

$$Moisture\ Content\ (\%) = \frac{wet\ weight - dry\ weight}{wet\ weight} \times 100$$

A typical range of moisture contents is 20 – 45% representing the extremes of wastes in an arid climate and in the wet season of a region having large precipitation. Values greater than 45% are however not uncommon. Moisture increases the weight of solid waste and therefore the cost of collection and transport. Consequently, waste should be insulated (protect) from rainfall or other extraneous water. Moisture content is a critical determinant in the economic feasibility.

Moisture content is a critical determinant in the economic feasibility of waste treatment and processing methods by incineration since energy (e.g. heat) must be supplied for evaporation of water and in raising the temperature of the water vapour.

Size of Waste Constituents:

The size distribution of waste constituents in the waste stream is important because of its significance in the design of mechanical separators and shredder and waste treatment process. This varies widely and while designing a system, proper analysis of the waste characteristics should be carried out.

Calorific Value:

Calorific value is the amount of heat generated from combustion of a unit weight of a substance, expressed as kcal/kg. The calorific value is determined experimentally using Bomb calorimeter in which the heat generated at a constant temperature of 25^{o}c from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water, the combustion water remains in the liquid state. However, during combustion the temperature of the combustion gases remains above 100^{O}c so that the water resulting from combustion is in the vapour state.

While evaluating incineration as a means of disposal or energy recovery, the following points should be kept in view:

- Organic material yields energy only when dry;
- The moisture contained as free water in the waste reduces the dry organic material per kilogram of waste and requires a significant amount of energy for evaporation; and
- The ash content of the waste reduces the proportion of dry organic material per kilogram of waste. It also retains some heat when removed from the furnace.

2. **Chemical Characteristics**

   A knowledge of chemical characteristics of waste is essential in determining the efficacy of any treatment process. Chemical characteristics include (i) chemical; (ii) bio-chemical; and (iii) toxic.

Chemical: Chemical characteristics include pH, Nitrogen, Phosphorus and Potassium (N-P-K), total Carbon, C/N ratio, and calorific value.

Bio-Chemical: Bio-Chemical characteristics include carbohydrates, proteins, natural fibre, and biodegradable factor.

Toxic: Toxicity characteristics include heavy metals, pesticides, insecticides, Toxicity test for Leachates (TCLP), etc.

Classification

A knowledge of the classes of chemical compounds and their Characteristics is essential in proper understanding of the behaviour of waste as it moves through the waste management system. The products of decomposition and heating values are two examples of the importance of chemical characteristics. Analysis identifies the compounds and the percent dry weights of each class. The rate and products of decomposition are assessed through chemical analysis. Calorific value indicates the heating value of solid waste. Chemical characteristics are very useful in assessment of potential of methane gas generation. The various chemical components normally found out in municipal solid waste are described below.

Lipids:

Included in this class of compounds are fats, oils and grease. The principal sources of lipids are garbage, cooking oils and fats. Lipids have high calorific values, about 38000 kcal/kg, which makes waste with a high lipid content suitable for energy recovery processes. Since lipids in the solid state become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition. They are biodegradable but because they have a low solubility in waste, the rate of biodegradation is relatively slow.

Carbohydrates:

Carbohydrates are found primarily in food and yard waste. They include sugars and polymers of sugars such as starch and cellulose and have the general formula $(CH_2O)_X$. Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane. Decomposing carbohydrates are particularly attractive for flies and rats and for this reason should not be left exposed for periods longer than is necessary.

Proteins:

Proteins are compounds containing carbon, hydrogen, oxygen and nitrogen and consist of an organic acid with a substituted amine group (NH_2). They are found mainly in food and garden wastes and comprise 5-10% of the dry solids in solid waste. Proteins decompose to form amino acids but partial decomposition can result in the production of amines, which have intensely unpleasant odours.

Natural Fibres:

This class includes the natural compounds, cellulose and lignin, both of which are resistant to biodegradation. They are found in paper and paper products and in food and yard waste. Cellulose is a larger polymer of glucose while lignin is composed of a group of monomers of which benzene is the primary member. Paper, cotton and wood products are 100%, 95% and 40% cellulose respectively. Since they are highly combustible, solid waste having a high proportion of paper and wood products, are suitable for incineration. The calorific values of oven dried paper products are in the range 12000 – 18000 kcal/kg and of wood about 20000 kcal/kg, which compare with 44200 kcal/kg for fuel oil.

Synthetic Organic Materials (Plastic):

In recent years, plastics have become a significant component of solid waste accounting for 5-7%. Plastic being non-bio-degradable, its decomposition does not take place at disposal site. Besides, plastic causes choking of drains and environmental pollution when burnt under uncontrolled condition. Recycling of plastics is receiving more attention, which will reduce the proportion of this waste component at disposal sites.

Non-combustibles:

Materials in this class are glass, ceramic, metals, dust, dirt, ashes and Construction. Non-combustibles account for 30-50% of the dry solids.

Chemical Characteristics of Municipal Solid Wastes in Indian Citie

Population Range(in millions)	Number of cities surveyed	Moisture%	Organic Matter %	Nitrogen as total. N%	Phosphorous as P_2O5 %	Potassium as K_2O%	C/N ratio	Calorific value in Kcal/kg
0.1-0.5	12	25.81	37.09	0.71	0.63	0.83	30.94	1009.89
0.5-1.0	15	19.52	25.14	0.66	0.56	0.69	21.13	900.61
1.0-2.0	9	26.98	26.89	0.64	0.82	0.72	23.68	980.05
2-5	3	21.03	25.60	0.56	0.69	0.78	22.45	907.18
>5	4	38.72	39.07	0.56	0.52	0.52	30.11	800.70

Problems due to improper disposal of solid waste

Impacts of Solid Waste on Human Health, Animals and Aquatics Life:

There are potential risks to environment and health from improper handling of solid wastes. Direct health risks concern mainly the workers in this field, who need to be protected, as far as possible, from contact with wastes. There are also specific risks in handling wastes from hospitals and clinics. For the general public, the main risks to health are indirect and arise from the breeding of disease vectors, primarily flies and rats.

Uncontrolled hazardous wastes from industries mixing up with municipal wastes create potential risks to human health. Traffic accidents can result from toxic spilled wastes. There is specific danger of concentration of heavy metals in the food chain, a problem that illustrates the relationship between municipal solid wastes and liquid industrial effluents containing heavy metals discharged to a drainage/sewerage system and /or open dumping sites of municipal solid wastes and the wastes discharged thereby maintains a vicious cycle including these some other types of problem are as follows.

- Chemical poisoning through chemical inhalation Uncollected waste can obstruct the storm
- water runoff resulting in flood
- Cancer
- Congenital malformations
- Neurological disease
- Nausea and vomiting
- Mercury toxicity from eating fish with high
- levels of mercury Plastic found in oceans ingested by birds
- Resulted in high algal population in rivers and sea.
- Degrades water and soil quality

Impacts of solid waste on environment

Loss of beauty (Aesthetic Effect)

Litter and discarded solid waste spoils the beauty of the area. The scene looks dirty and most people tend to the already spread waste

Highly Odorous

Stored or collected solid waste produces on obnoxious odour. Solid waste releases this smell during the decomposition process.

Toxic Gases

Municipal solid waste disposal sites or land fill sites produces toxic gases like Hydrogen Sulphide (H_2S), Methane (CH_4), Carbon dioxide (CO_2). These gases are harmful to human's health.

Spread of Diseases

Dumping of solid waste invites various diseases. The common diseases observed around solid waste disposal area are typhoid, bacillary dysentery, amoebic, dysentery, diarrhoea, Cholera, etc. Open dumping of solid waste creates unhygienic environmental conditions, and directly affects public health. Along with mosquitoes, flies and rodents are very common in and around the dump yards.

Environmental Pollution

During the process of decomposition and burning of solid waste, toxic gases are which are harmful to our health. Many times we find waste at dumping sites burnt to reduce the total volume of solid waste. It releases toxic gases and dust or suspended particles.

Water Pollution

Solid waste dumping sites or improper land fill sites often face problems of leachate or percolation of waste water. Toxic substances get mixed with ground water channel, river, lakes, well and any nearby water .It creates contamination of pathogenic organisms in water bodies.

Soil

Microorganism plays a very important role in soil decomposition. Due to dumping of toxic substances like plastic bags, or any synthetic material; microorganisms die and further process of decomposition is hampered. Sometimes soil becomes acidic or alkaline due to solid waste.

Effect on Bird Diversity

Many birds migrate from a particular area to other areas due to bad smell of waste.

FUNCTIONAL ELEMENTS:

The activities involved with the management of solid wastes from the point of generation to final disposal have been grouped into six functional elements:

1) Waste generation
2) On-site handling, storage and processing
3) Collection
4) Transfer and transport
5) Processing and recovery and
6) Disposal.

Description of the functional elements of a solid waste management

- ✓ Waste generation: Those activities in which materials are included as no longer being of value are either thrown away or gathered tighter for disposal.
- ✓ On-site handling, storage and processing: Those activities associated with the handling, storage and processing of solid wastes at or near the point of generation
- ✓ Collection: those activities associated with the gathering of solid waste and the hauling of wastes after collection to the location where the collection vehicle is emptied.
- ✓ Transfer and Transport: those activities associated with
    - The transfer of wastes from the smaller collection vehicle to the larger transport equipment.
    - The subsequent transport of the waste, usually over long distance, to the disposal site.
- ✓ Processing and Recovery: Those techniques, equipment and facilities used to improve the efficiency of the other functional elements and to recover usable materials, conversion products and energy from solid waste.
- ✓ Disposal: Those activities associated with the ultimate disposal of solid wastes, including those wastes collected and transported directly to a landfill site, semisolid wastes (sludge) from waste water treatment plants, incinerator residue, compost or the other substance from the various solid-waste processing plants that are of no future use.

1. Waste Generation:

Waste generation encompasses activities in which materials are identified as no longer being of value (in their present form) and are either thrown away or gathered together for disposal. Waste generation is, at present, an activity that is not very controllable. In the future, however, more control is likely to be exercised over the generation of wastes. Reduction of waste at source, although not controlled by solid waste managers, is now included in system evaluations as a method of limiting the quantity of waste generated.

2. Waste Handling, Sorting, Storage, and Processing at the Source:

The second of the six functional elements in the solid waste management system is waste handling, sorting, storage, and processing at the sourceWaste handling and sorting involves the activities associated with management of wastes until they are placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection. Sorting of waste components is an important step in the handling and storage of solid waste at the source. For example, the best place to separate waste materials for reuse and recycling is at the source of generation.

Households are becoming more aware of the importance of separating newspaper and cardboard, bottles/glass, kitchen wastes and ferrous and non-ferrous materials. On-site storage is of primary importance because of public health concerns and aesthetic consideration. Unsightly makeshift containers and even open ground storage, both of which are undesirable, are often seen at many residential and commercial sites. The cost of providing storage for solid wastes at the source is normally borne by the household in the case of individuals, or by the management of commercial and industrial properties. Processing at the source involves activities such as backyard waste composting.

3. Collection: The functional element of collection includes not only the gathering of solid wastes and recyclable materials, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be materials processing facility, a transfer station, or a landfill disposal site.

4. Sorting, Processing and Transformation of Solid Waste:
The sorting, processing and transformation of solid waste materials is the fourth of the functional elements. The recovery of sorted materials, processing of solid waste and transformation of solid waste that occurs primarily in locations away from the source of waste generation are encompassed by this functional element. Sorting of commingled (mixed) wastes usually occurs at a materials recovery facility, transfer stations, combustion facilities, and disposal sites. Sorting often includes the separation of bulky items, separation, of waste components by size using screens, manual separation of waste components, and separation of ferrous and non-ferrous metals. Waste processing is undertaken to
recover conversion products and energy.

5.Transfer and Transport:
The functional element of transfer and transport involves two steps:

(i) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and

(ii) (ii) the subsequent transport of the wastes, usually over long distances, to a processing or disposal site. The transfer usually takes place at a transfer station.

6.Disposal:
The final functional element in the solid waste management system is disposal. Today the disposal of wastes by land-filling or uncontrolled dumping is the ultimate fate of all solid wastes, whether they are residential wastes collected and transported directly to a landfill site, residual materials from Materials Recovery Facilities (MRFs), residue from the combustion of solid waste, rejects of composting, or other substances from various solid waste-processing facilities.

A municipal solid waste landfill plant is an engineered facility used for disposing of solid wastes on land or within the earth's mantle without creating nuisance or hazard to public health or safety, such as breeding of rodents and insects and contamination of groundwater.

Typical generation rates

Typical unit waste-generation rates for municipal and selected commercial and industrial sources are tagged in table 1 and 2 respectively. Because waste-generation practices are changing so rapidly, the presentation of site-specific waste-generation data is meaningless. where waste-generation data is not available the data presented in table 1 that can be used for purposes of estimation of waste.

Table 1: typical per capita solid-waste generation rates

Source	Unit rate, Kg/capita/day	
	Range	Typical
Municipal (residential & commercial)	0.75-2.50	1.6
Industrial	0.4-1.6	0.9
Demolition	0.05-0.4	0.3
Others	0.05-0.3	0.2

Table 2: typical commercial and industrial waste generation rates

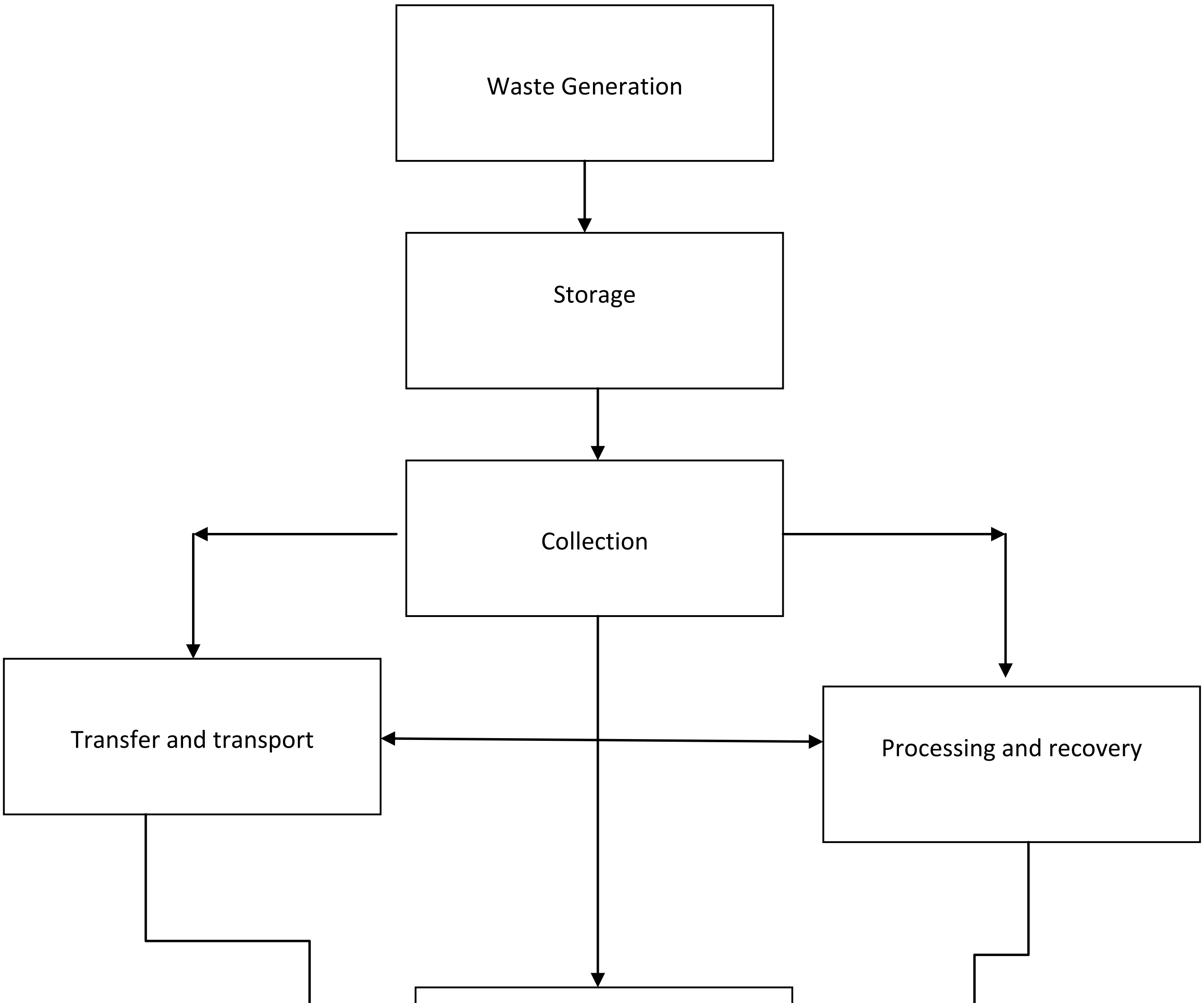
Source	Unit	Range
Office buildings	Kg/employee/day	0.5-1.1
Restaurants	Kg/employee/day	0.2-0.8
Canned and frozen foods	tonnes/tonne of raw product	0.04-0.06
Printing and publishing	tonnes/tonne of raw paper	0.08-0.10
Automotive	tonnes/vehicle produced	0.6-0.8
Rubber	tonnes/tonne of raw rubber	0.01-0.3

Table 3: Typical densities for solid wastes components and mixtures

Item	Density, kg/m^3	
	Range	Typical
Food Wastes	120-480	290
Paper	30-130	85
Cardboard	30-80	50
Plastics	30-130	65
Textiles	30-100	65
Rubber	90-200	130

Leather	90-260	160
Garden trimmings	60-225	105
Wood	120-320	240
Glass	160-480	195
Tin cans	45-160	90
Non-ferrous metals	120-1200	320
Dirt, ashes, brick	320-960	480
	Municipal solid wastes	
Un-compacted	90-180	130
Compacted	180-450	300
	In landfill	
Compacted normally	350-550	475
Well compacted	600-750	600

Interrelationship of functional elements comprising solid-waste Management system



Estimation of solid-waste quantities

The quantity and general composition of the waste material that is generated is of critical importance in the design and operation of solid waste management systems. Unfortunately, reliable quantity and composition data are difficult to obtain because most measurements are of the quantities collected or disposed at a landfill.

The solid waste can be analysed in two different ways:

1. Load-Count Analysis.
2. Mass-Volume Analysis.

Load-count Analysis:

In this method, the quantity and composition of solid wastes are determined by recording and the estimated volume and general composition of each load of waste delivered to a landfill or transfer station during a specified period of time. The total mass and mass distribution by composition is determined using average density data for each waste category is prescribed in table no: 3.

Mass-Volume Analysis:

This method of analysis is similar to the above method with the added feature that the mass of each load is also is recorded. Unless the density of each waste category is determined separately, the mass distribution by composition must be derived using density values.

On site Handling, Storage, and processing

On-site Handling:

On-site Handling refers to the activities associated with the handling the solid wastes until they are placed in the containers used for their storage before collection. Depending on the type of collection service, handling may also be required to move loaded containers to the collection point and to return the empty containers to the point where they are stored between collections.

Handling of Domestic, Commercial and Industrial solid wastes:

Handling of Domestic Solid Wastes:

Typically, domestic wastes accumulated at several locations in and around low and medium rise residential dwellings are placed in large storage containers to await removal by the waste-collection agency. Where curb collection is used, the resident is also responsible for placing the loaded storage containers at the curb and returning the empty containers to their storage location.

Handling of Commercial and Industrial solid wastes:

In commercial and industrial building, solid wastes that accumulate in the offices or the work locations usually are collected in relatively large containers mounted on rollers. Once filled , these containers are moved by the means of the service elevator, if there is one and emptied in to 1) Large storage containers, 2) compactors used in the conjunction with the storage containers, 3) stationary compactors that can compress the material in to bales or specially designed containers 4)other processing equipments such as incinerators.

ON-SITE STORAGE

Factors that must be considered in the on-site storage of solid waste include

1. The type of the container to be used
2. The container location
3. Public health and aesthetics
4. The collections methods

Containers:

To a large extent, the types and capacities of the containers used depend up on the characteristics of the solid wastes to be collected, the collection frequency, and the space available for the placement of containers. The types and capacities of containers now commonly used for on-site storage of solid waste are summarized in table no: 4. Because of increasing costs (including the cost of labour, workers, fuel and equipment cost) there is a strong movement in waste collection field towards the use of large containers that can be emptied mechanically using a vehicle equipped with an artificial pick up mechanism.

Table 4: Data on the types and sizes of containers used for the on-site storage of solid wastes

		Capacity	
Container type	Unit	Range	Typical
Small capacity			
Plastic or metal (office type)	L	16-40	28
Plastic or galvanized metal	L	75-150	120
Barrel: Plastic, aluminum, fiber	L	75-250	120
Plastic container with wheels	L	300-380	340
Disposable plastic bags	L	75-210	120
Medium capacity			
Side or top loading	m^3	0.75-9	3
Large capacity			
Open top, roll off (debris boxes)	m^3	9-38	27

Used with stationary compactor	m^3	15-30	23
Equipped with self-contained compaction mechanism	m^3	15-30	23
Trailer-mounted, open top	m^3	15-38	27
Enclosed, equipped with self-contained compaction mechanism	m^3	15-30	27

Container Locations:

In newer residential areas, containers for solid waste usually are placed by the side or rear of the house. In older residential areas containers are located in alleys. In low-rise apartments large containers are often placed in specially designed enclosures. In high –rise apartments storage containers are located in a basement or ground floor service area.

Debris box

Different types of waste collection vehicles

Waste collection vehicle with compactor

Land-fill compactor

Collection of solid waste:

Functional elements in the collection of solid wastes

A. The types of collection services and components
B. The types of collection systems
C. An analysis of collection system
D. The general methodology involved in setting up collection routes

Collection services

The various types of collections services now used for municipal and commercial sources are

1) Municipal Collection Services
2) Commercial- industrial Collection services

Municipal collection services:

A variety of collection services are used through the world, the three most common are curb, alley and back yard collection. Curb collection has gained popularity because labour costs for collection can be minimized. In future it appears that the use of large containers which can be emptied mechanically with an articulated container pickup mechanism will be the most common method used for the collection of municipal wastes.

Commercial- industrial Collection services:

The collection service provided to large apartment buildings, residential complexes, commercial and industrial activities typically is centred around the use of large movable and stationary containers and large stationary compactors. Compactors are the type that can be used to compress material directly in to large containers or to form bales that are then placed in large containers.

COLLECTION COMPONENTS:

waste collection does not mean merely the gathering of wastes, and the process includes, as well, the transporting of wastes to transfer stations and/or disposal sites. To elaborate, the factors that influence the waste collection system include the following.

i) Collection points: These affect such collection system components as crew size and storage, which ultimately control the cost of collection. Note that the collection points depend on locality and may be residential, commercial or industrial.

(ii)Collection frequency: Climatic conditions and requirements of a locality as well as containers and costs determine the collection frequency. In hot and humid climates, for example, solid wastes must be collected at least twice a week, as the decomposing solid wastes produce bad odour and leachate.
And, as residential wastes usually contain food wastes and other putrescible (rotting) material, frequent collection is desirable for health and aesthetic reasons. Besides climates, the quality of solid waste containers on site also determines the collection frequency. For instance, while sealed or closed containers allow collection frequency up to three days, open and unsealed containers may require daily collection. Collection efficiency largely depends on the demography of the area (such as income groups, community, etc.), where collection takes place.
While deciding collection frequency, therefore, you must consider the following:

- cost, e.g., optimal collection frequency reduces the cost as it involves fewer trucks, employees and reduction in total route distance;
- storage space, e.g., less frequent collection may require more storage space in the locality;
- Sanitation, e.g., frequent collection reduces concerns about health, safety and nuisance associated with stored refuse.

(iii) Storage containers:

Proper container selection can save collection energy, increase the speed of collection and reduce crew size. Most importantly, containers should be functional for the amount and type of materials and collection vehicles used. Containers should also be durable, easy to handle, and economical, as well as resistant to corrosion, weather and animals. In residential areas, where refuse is collected manually, standardised metal or plastic containers are typically required for waste storage. When mechanised collection systems are used, containers are specifically designed to fit the truck-mounted loading mechanisms.

While evaluating residential waste containers, consider the following:

- Efficiency, i.e., the containers should help maximize the overall collection efficiency.
- Convenience, i.e., the containers must be easily manageable both for Residents and collection crew.
- Compatibility, i.e., the containers must be compatible with collection equipment.
- Public health and safety, i.e., the containers should be securely covered and Stored.
- Ownership, i.e., the municipal ownership must guarantee compatibility with collection equipment.

(iv) Collection crew :

The optimum crew size for a community depends on labour and equipment costs, collection methods and route characteristics. The size of the collection crew also depends on the size and type of collection vehicle used, space between the houses, waste generation rate and collection frequency. For example, increase in waste generation rate and quantity of wastes collected per stop due to less frequent collection result in a bigger crew size. Note also that the collection vehicle could be a motorised vehicle, a pushcart or a trailer towed by a suitable prime mover (tractor, etc.). It is possible to adjust the ratio of collectors to collection vehicles such that the crew idle time is minimised. However, it is not easy to implement this measure, as it may result in an overlap in the crew collection and truck idle time. An effective collection crew size and proper workforce management can influence the productivity of the collection system. The crew size, in essence, can have a great effect on overall collection costs. However, with increase in collection costs, the trend in recent years is towards:

- decrease in the frequency of collection;
- increase in the dependence on residents to sort waste materials;
- Increase in the degree of automation used in collection.
- This trend has, in fact, contributed to smaller crews in municipalities

(v) Collection route:

The collection programme must consider the route that is efficient for collection. An efficient routing of collection vehicles helps decrease costs by reducing the labour expended for collection. Proper planning of collection route also helps conserve energy and minimise working hours and vehicle fuel consumption. It is necessary therefore todevelop detailed route configurations and collection schedules for the selected collection system. The size of each route, however, depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad, embankments, rivers and roads with heavy traffic, can be considered to divide route territories. Routing (network) analyses and planning can:

- increase the likelihood of all streets being serviced equally and consistently;
- help supervisors locate or track crews quickly;
- Provide optimal routes that can be tested against driver judgement and experience.

(vi)Transfer station:

A transfer station is an intermediate station between final disposal option and collection point in order to increase the efficiency of the system, as collection vehicles and crew remain closer to routes. If the disposal site is far from the collection area, it is justifiable to have a transfer station, where smaller collection vehicles transfer their loads to larger vehicles, which then haul the waste long distances. In some instances, the transfer station serves as a pre-processing point, where wastes are dewatered, scooped or compressed. A centralised sorting and recovery of recyclable materials are also carried out at transfer stations The unit cost of hauling solid wastes from a collection area to a transfer station and then to a disposal site decreases, as the size of the collection vehicle increases. This is due to various reasons such as the following:

- labour costs remain constant;
- the ratio of payload to vehicle load increases with vehicle size;
- the waiting time, unloading time, idle time at traffic lights and driver rest

period are constant, regardless of the collection vehicle size.

Curb collection manually

Curb collection mechanically


Solid waste


Waste converted in to Bales

Types of collection systems:

Collection systems are divided in to two types based up on their mode of operation.

1. Hauled-Container Systems (HCS)
2. Stationary-Container Systems (SCS)

Hauled-Container Systems (HCS):

Collection systems in which the containers used for the storage of wastes are hauled to the processing, transfer, or to disposal site, emptied and returned to either their original location are defined as Hauled-container system. There are two main types of hauled-container systems 1) tilt-frame container 2) trash-trailer. Data related to the collection vehicles and containers used with this system are tabulated in table no: 5.The collector is responsible for driving the vehicle, loading full containers and unloading the empty containers and emptying the contents of the container at the disposal site. In some cases, for safety reasons, both driver and helper are used. Systems that use tilt-frame loaded vehicles and large containers are often called Drop boxes, are ideally suited for the collection of all types of solid waste and rubbish from locations where the generation rate warrants the use of large containers.

Open top containers are used routinely at warehouses and constructions sites. Large containers used in conjunction with stationary compactors. This type is commonly used at commercial and industrial services and at transfer stations. Because of the large volume that can be hauled, the use of tilt-frame hauled-container systems has become widespread, especially among private collectors servicing industrial accounts. The application of trash-trailers is similar to that of tilt-frame container systems. Trash-trailers are better for the collection of especially heavy rubbish, timber and metal scrap and often used for the collection of demolition wastes at construction sites.

Tilt-Frame Container

Trash trailer

Table 5 Data on vehicles and containers used with various collection systems

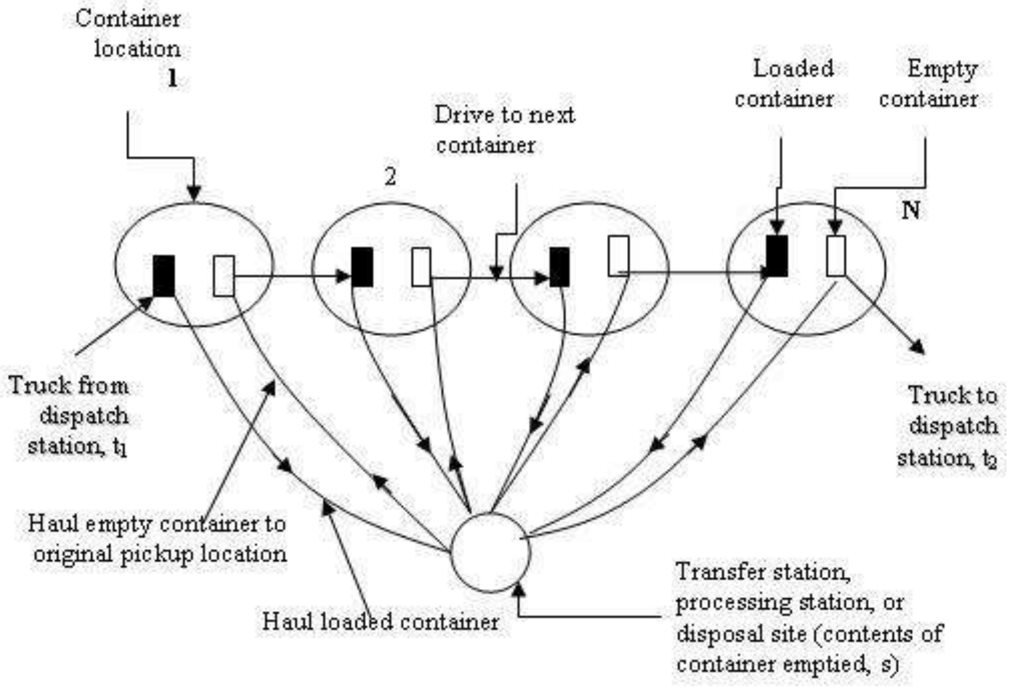
Vehicle	Collection container type	Range of container capacities m^3
	Hauled-container system	
Tilt-frame	Open top, also called Debris boxes	8-40
	Used in conjunction with stationary compactor	10-30
	Equipped with self-contained compaction mechanism	15-30
Truck-tractor	Open-top trash trailers	10-30
	Enclosed trailer-mounted containers	
	Equipped with self-contained compaction mechanism	15-30
	Stationary-Container System	
Compactor, mechanically loaded	Open top and enclosed top and side-loading	0.6-8

<u>Stationary-Container System (SCS):</u>

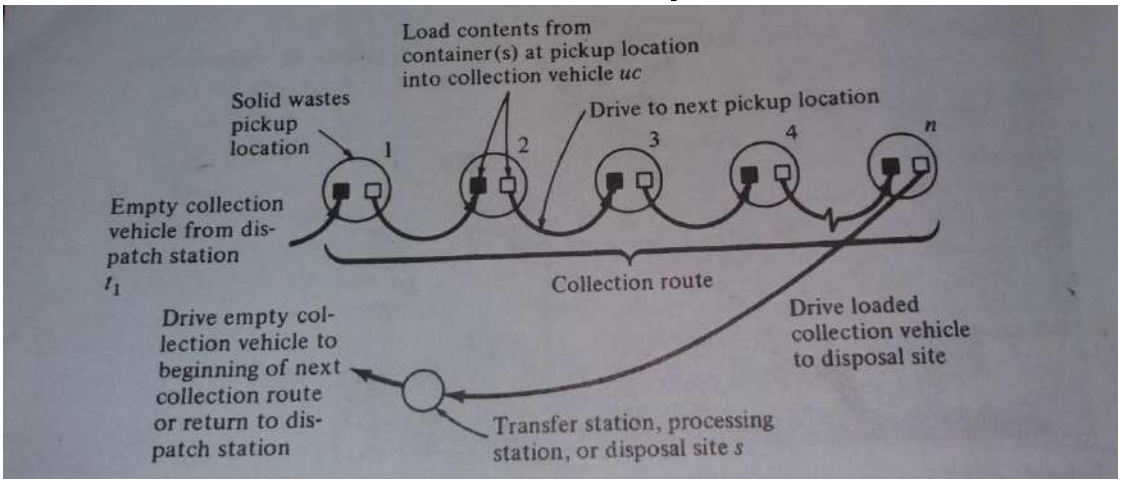
Collection systems in which the containers used for the storage of waste remain at the point of waste generation, except when moved for collections are defined as Stationary-Container Systems. Labour requirements for mechanically loaded stationary-containers systems are essentially the same as for hauled-container systems. There are two types of stationary-containers system: 1) SCS with self-loading compactors 2) SCS in which manually loaded vehicles.

Container size and utilization are not as critical in SCS using self-loading collection vehicles equipped with a compaction mechanism as they in hauled-container system. Trips to the disposal site, transfer station, or processing station are made after the contents of a number of containers have been collected and compacted and the collection vehicle is full. Because a variety of container sizes and types are available, these systems may be used for the collection of all types of wastes.

Sketch for collection of solid waste



Hauled –Container System



Stationary-Container systems

Note: solid wastes can be resolved in to four unit operations namely pick-up, haul, at- site and off route. These unit operations are defined in table 6

COLLECTION OF SOLID WASTE (used mainly in India):

Points of Collection Options
Door-to-Door

• Involves the labourers entering the premises, collecting garbage from a storage area and emptying it into the collection vehicle.

Building-to-Building

• Collecting garbage from outside/adjacent to buildings, along streets or valley ways.

Bell Collection

• Music based collection method, where garbage collection vehicles play special music or callers shout "dustbin" as they collect garbage.

Kerbside Collection

• Closed containers placed on roadside for collection.
• Containers are returned to pickup point after emptying.

Handcart Collection

• Handcart collection is a type of a kerbside collection system.
• Labourers collect waste stored in containers, bags of waste left at the kerbside or collect waste directly from the resident.
• Handcarts must transfer their loads to a tractor, lorry or compactor for transportation to the disposal site.
• In areas of the town/city that have narrow or congested roads, handcarts are often used for collection.

Waste Pooling Sites

• A centralized collection point typically located on public property no more than a specified distance from any waste generator.

Some other types of COLLECTION METHODS

Evaluation of Methods of Collection
Methods to collect residential and commercial solid waste from any point of collection fall into one of the following categories:

• Manual collection.
• Semi-automated collection.
• Automated collection.

Handcart Collection:

• Generally, handcart collection is undertaken as primary collection only. Loads must be transferred to a stationary trailer or collection vehicle for transportation to the final disposal site. This is preferable to handcarts emptying their loads into public bins or other community collection points.
• Garbage should be loaded into handcarts in disposable bags, so that these may be easily transferred to transportation vehicles. Alternatively, garbage can be loosely placed into six to eight 30-40 litre buckets within the handcart (a 'bin cart'), which can subsequently be lifted out and emptied one by one. There should be a liner within handcarts so that loosely placed garbage can be easily lifted into a transfer vehicle. It is also useful to place a liner in 'bin carts' to catch any overspill waste from the bins.
• Handcart collection is suitable for sweeping street waste and is not appropriate for collecting bulky garbage.
• Handcarts can be used for collecting drain cleanings. However, the buckets should not be completely filled or else they will be too heavy for one person to lift.
• Handcart collection is very expensive compared to other forms of collection (refer to graph below). This is mainly due to the high labour costs (2-3 workers per handcart) and the low tonnage carried per load (around 120kg).

• Handcart collection is useful and/or necessary in some locations – narrow roads, congested areas, markets, common bins, etc.
• It is vital to restrict handcart usage to only essential places in order to reduce overall costs.

Hand Tractor Collection:

• Hand tractor collection is moderately expensive.
• Hand tractors have a number of other disadvantages:
  - ✓ They must be unloaded manually, which takes at least 20 minutes per load.
  - ✓ They are poor at reversing, especially up slopes and under soft, wet conditions (e.g. at disposal sites).They are very slow and hold up traffic.
  - ✓ Hand tractor usage should be restricted to narrow roads in residential areas that cannot be accessed by other Motorised vehicles.

Collection routes:

Once the equipment and labour requirements have been determined, collection routes must be laid out so both the work force and equipment are used efficiently. In general the layout of collection routes is a trial and error process.

Some of the factors that should be taken in to consideration when laying out routes are as follows:

1. Existing company policies and regulations related to such items as the point of collection and frequency of collection must be identified.
2. Existing system conditions such as crew size and vehicle types must be co-ordinated.
3. Wastes generated at traffic-congested locations should be collected as early in a day as possible.
4. Sources at which extremely large quantities of wastes are generated should be serviced during the first part of the day.
5. Scattered pick up points where small quantities of solid wastes are generated should if possible be serviced during one trip or on the same day, if they receive same collection frequency.

COLLECTION VECHICLE ROUTING:

Efficient routing and re-routing of solid waste collection vehicles can help decrease costs by reducing the labour expended for collection. Routing procedures usually consist of the following two separate components:

(i) Macro-routing:

Macro-routing, also referred to as route-balancing, consists of dividing the total collection area into routes, sized in such a way as to represent a day's collection for each crew. The size of each route depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such a s railroad embankments, rivers and roads with heavy competing traffic, can be used to divide route territories. As much as possible, the size and shape of route areas should be balanced within the limits imposed by such barriers.

(ii)Micro-routing:

Using the results of the macro - routing analysis, micro routing can define the specific path that each crew and collection vehicle will take each collection day. Results of micro - routing analyses can then be used to readjust macro - routing decisions. Micro – routing analyses should also include input and review from experienced collection drivers.

(iii)Districting:

Districting is the other method for collection route design. For larger areas it is not possible for one institution to handle it then the best way is to sub divide the area and MSW collection districting plan can be made. This routing will be successful only when road network integrity is good and the regional proximity has been generated. The heuristic (i.e., trial and error) route development process is a relatively simple manual approach that applies specific routing patterns to block configurations. The map should show collection, service garage locations, disposal or transfer sites, one-way streets, natural barriers and areas of heavy traffic flow.

<u>Layout of routes:</u>

The layout of collection routes is a four-step process.

Step 1: prepare location maps.

On a relatively large-scale map of the area to be serviced, the following data should be plotted for each solid-waste pick up point: location, number of containers, collection frequency and if a stationary-container system with self loading compactors is used, the estimated quantity of wastes to be collected to be collected at each pickup location.

Step 2: prepare data summaries:

Estimate the quantity of wastes to be collected from pickup locations serviced each day that the collection operation is to be conducted. Where a SCS is used, the number of locations that will be serviced during each pick up cycle must also be determined.

Step 3: preliminary layout:

Preliminary collection routes starting from the dispatch station or where the collection vehicles are parked. A route should be laid out that connects all the pickup locations to be serviced during each collection day. The route should be laid out so that the last location is nearest to the disposal site.

Step 4: develop balance routes

After the preliminary collection routes have been laid out, the haul distance for each route should be determined. Next, determine the labour requirements per day and check against the available work times per day. In some cases it may be necessary to readjust the collection routes to balance the work load and the distance travelled. After the balanced routes have been established, they should be drawn on the master map.

Routes should then be traced onto the tracing paper using the following rules:

1. Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area.
2. The collection route should start as close to the garage or motor pool as possible, taking into account heavily travelled and one-way streets
3. Collection from heavily travelled streets should not be carried out during rush hours.
4. In the case of one-way streets, it is best to start the route near the upstream end of the street, working down it through the looping process.
5. Services on dead-end streets can be considered as services on the street segment that they intersect, since they can only be collected by passing down that street segment. To keep right turns to a minimum, collect the dead-end streets when they are to the left of the truck. Collections from dead-end streets must be made by walking down, backing down or making a u-turn at the dead-end.

6. When practical, solid waste on a steep hill should be collected on both sides of the street while the vehicle is moving downhill. This facilitates safety, ease and speed of collection. It also lessens wear of the vehicle and conserves gas and oil.
7. Higher elevations should be at the start of the route.
8. For collection from one side of the street at a time, it is generally best to route with many counter-clockwise turns around blocks.
9. For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the street before looping counter clockwise.
10. For certain block configurations within the route, specific routing patterns should be applied that best fit the layout.

TRANSFER AND TRANSPORT OF WASTES

A **transfer station** is a building or processing site for the temporary deposition of waste. Transfer stations are often used as places where local waste collection vehicles will deposit their waste cargo prior to loading into larger vehicles. These larger vehicles will transport the waste to the end point of disposal in an incinerator, landfill, or hazardous waste facility, or for recycling

Transfer stations are sometimes collected with material recovery facilities and with localized mechanical biological treatment systems to remove recyclable items from the waste stream.

The following factors that affect the selection of a transfer station:

- Types of waste received.
- Transfer station Processes required in recovering material from wastes.
- Required capacity and amount of waste storage desired.
- Types of collection vehicles using the facility.
- Types of transfer vehicles that can be accommodated at the disposal facilities.
- Site topography and access

Transfer stations types:
Depending on the size, transfer stations can be either of the following two types:
(i)Small to medium transfer stations: These are direct-discharge stations that provide no intermediate waste storage area. The capacities are generally small (less than 100 tonnes/day) and medium (100 to 500 tonnes/day). Depending on weather, site aesthetics and environmental concerns, transfer operations of this size may be located either indoor or outdoor. More complex small transfer stations are usually attended during hours of operation and may include some simple waste and materials processing facilities. For example, it includes a recyclable material separation and processing centre. The required overall station capacity (i.e., the number and size of containers) depends on the size and population density of the area served and the frequency of collection.

(ii)Large transfer stations: These are designed for heavy commercial use by private and municipal collection vehicles. The typical operational procedure for a larger station is as follows:

- when collection vehicles arrive at the site, they are checked in for billing, weighed and directed to the appropriate dumping area;
- collection vehicles travel to the dumping area and empty the wastes into awaiting trailer, a pit or a platform;
- after unloading, the collection vehicle leaves the site, and there is no need to weigh the departing vehicle, if its weight (empty) is known;

- ➢ Transfervehicles are weighed either during or after loading. If weighed during loading, trailers can be more consistently loaded to just under maximum legal weights and this maximises payloads and minimises weight violations.

Transfer stations should be located conveniently close to all the communities they serve, but not too close to people's homes or factories, schools, hospitals, etc. so that they cause a nuisance. They should also have access to major roads leading to the treatment or disposal sites.

Transfer stations have many advantages:

- They reduce the overall traffic levels by using fewer but larger-capacity vehicles, which reduces traffic congestion and pollution.
- If primary collection vehicles have to drive longer distances to the disposal site they are more likely to be tempted to save time by illegally dumping the waste at the side of the road. Transfer stations prevent this happening.
- In areas with a low population density it is cheaper to have a transfer station that incorporates short-term storage of the waste. Small carts can deposit their waste here daily and a larger vehicle can transport the stored waste to the disposal site every few days.
- Consolidating the waste into fewer vehicles reduces vehicle wear, the need for maintenance and fuel consumption.
- Waste can be screened so that recyclable items or inappropriate waste (like tyres and vehicle batteries, which should not go to a landfill) can be taken out.
- Transfer stations reduce traffic at the disposal facility. Since fewer vehicles go to the final disposal site, traffic congestion can be avoided, the cost of operation can be minimised and public safety is improved.

VEHICLES USED FOR TRANSPORTATION OF SOLID WASTE:

Collection vehicles:

Almost all collections are based on collector and collection crew, which move through the collection service area with a vehicle for collecting the waste material. The collection vehicle selected must be appropriate to the terrain, type and density of waste generation points, the way it travels and type and kind of material. It also depends upon strength, stature and capability of the crew that will work with it. The collection vehicle may be small and simple (e.g., two-wheeled cart pulled by an individual) or large, complex and energy intensive (e.g., rear loading compactor truck). The most commonly used collection vehicle is the dump truck fitted with a hydraulic lifting mechanism. A description of some vehicle types follows:

(i)Small-scale collection and muscle-powered vehicles: These are common vehicles used for waste collection in many countries and are generally used in rural hilly areas. As Figure illustrates, these can be small rickshaws, carts or wagons pulled by people or animals, and are less expensive, easier to build and maintain compared to other vehicles: They are suitable for densely populated areas with narrow lanes, and squatter settlements, where there is relatively low volume of waste generated. Some drawbacks of these collection vehicles include limited Travel range of the vehicles and weather exposure that affect humans and animals.

(ii)Non-compactor trucks: Non-compactor trucks are efficient and cost effective in small cities and in areas where wastes tend to be very dense and have little potential for compaction.

When these trucks are used for waste collection, they need a dumping system to easily discharge the waste. It is generally required to cover the trucks in order to prevent residue flying off or rain soaking the wastes. Trucks with capacities of 10 –12 m^3 are effective, if the distance between the disposal site and the collection area is less than 15 km. If the distance is longer, a potential transfer station closer than 10 km from the collection area is required. Non-compactor trucks are generally used, when labour cost is high. Controlling and operating cost is a deciding factor, when collection routes are long and relatively sparsely populated.

(iii)Compactor truck:
Compaction vehicles are more common these days, generally having capacities of 12 –15 m^3due to limitations imposed by narrow roads. Although the capacity of a compaction vehicle's similar to that of a dump truck, the weight of solid wastes collected per trip is 2 to 25 times larger since the wastes are hydraulically compacted.

Purpose of processing of solid waste:
The processing of wastes helps in achieving the best possible benefit from every functional element of the solid waste management (SWM) system and, therefore, requires proper selection of techniques and equipment for every element. Accordingly, the wastes that are considered suitable for further use need to be paid special attention in terms of processing, in order that we could derive maximum economical value from them.
The purposes of processing, essentially, are

(i)Improving efficiency of SWM system:
Various processing techniques are available to improve the efficiency of SWM system. For example, before waste papers are reused, they are usually baled to reduce transporting and storage volume requirements. In some cases, wastes are baled to reduce the haul costs at disposal site, where solid wastes are compacted to use the available land effectively. If solid wastes are to be transported hydraulically and pneumatically, some form of shredding is also required. Shredding is also used to improve the efficiency of the disposal site.

ii) Recovering material for reuse: Usually, materials having a market, when present in wastes in sufficient quantity to justify their separation, are most amenable to recovery and recycling. Materials that can be recovered from solid wastes include paper, cardboard, plastic, glass, ferrous metal, aluminium and other residual metals.

(iii)Recovering conversion products and energy:
Combustible organic materials can be converted to intermediate products and ultimately to usable energy. This can be done either through incineration, pyrolysis, composting or bio-digestion. Initially, the combustible organic matter is separated from the other solid waste components. Once separated, further processing like shredding and drying is necessary before the waste material can be used for power generation.

A. Purpose:
•Modify the physical characteristics to facilitate removal of desired component.
•Remove specific components or contaminants.
•Prepare the material for subsequent uses.

B. Size Reduction:

•Size reduction is the process by which as collected materials are mechanically reduced in size.

•Object is to obtain a uniform final product that is reduced in size potentially reducing storage and shipping course. Size reduction does not necessarily mean volume reduction. Shredded paper occupies more space than the parent stock.

•Shredders include hammer mill, flail mill and shear shredder and usually involve metal parts revolving against one another.

- Glass crushers.

•Wood grinders include chippers, such as local tree cutters use, to reduce the branches to chips and tub grinders. Once the wood is broken up, the finer pieces can be used as raw material for composting and the larger pieces can be used as a fuel.

C. Screening

•Screening is a unit operation used to separate mixtures of materials of different sizes into two or more size fractions by means of screen surfaces.

•Object is to:

- Remove oversized material
- Remove undersized material
- Separate into light (combustible, paper) and heavy (noncombustible, glass) fractions.
- Screening devices include:
- Vibrating screens
- Rotary screens
- Disc screens

D. Other Processes:

- **Density Separation** (Air Classification) is the unit process used to separate light materials such as paper and plastic from heavy materials such as metals based on weight difference in the air stream. In solid waste the light fraction is typically organic while the heavy fraction is typically inorganic. Used to separate glass from plastic in a commingled situation. - Magnetic Separation is the operation by which ferrous metals are separated from the waste stream utilizing magnetic principals. Used to separate tin cans from aluminium in a commingled situation.
- **Densification** (compaction) is a unit operation used to increase the density of the material so that it can be stored and transported more cheaply and as a means of preparing densified refuse-derived fuels and includes balers and can crushers.

Method of Segregation of Solid Waste:

Segregation or sorting can be carried out manually or through semi- mechanised and fully mechanized systems.

Manual sorting operation:

Manual sorting operation comprises of,

1. Unloading the waste

2. Manually (with protective measures) spreading the waste

3. Hand picking (with protective measures) visually identifiable waste for reuse

4. Collecting and stockpiling the remaining waste

Semi-mechanized sorting operation:

Semi-mechanized sorting operations consists of,

1. Unloading of waste (mechanized)

2. Loading of waste on conveyor belts (mechanized)

3. Hand picking of visually identifiable waste off the belt for reuse (manual)

4. Collecting, stocking and reloading the remaining waste (mechanized)

Fully-mechanized sorting operation:

Fully-mechanized sorting operations comprise of,

1. Unloading of waste

2. Size reduction of waste through shredders and crushers

3. Size separation of waste using screening devices

4. Density separation of waste

5. Magnetic separation of waste

6. Compaction of waste through balers/crushers

7. Reloading of waste

UNIT – V

SOLID WASTE MANAGEMENT AND DISPOSAL

SYLLABUS:

Engineered systems for solid waste management (refuse, reduce, reuse, recover, recycle), Reuse of solid waste materials, processing techniques, Materials recovery system, Recovery of biological, thermal conversion products, Recovery of energy from conversion products, Recovery of segregated waste materials, Ultimate disposal of solid waste, Land filling, incineration, composting.

LEARNING OUTCOMES:

To learn about principles of waste management

Understand the concept of principles of waste management.

Understand the concept of composting.

Understand the concept of incineration.

Central principles of waste management:

There are a number of concepts about waste management which vary in their usage between countries or regions. Some of the most general, widely used concepts include:

The waste hierarchy refers to the "3 Rs" reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimisation. The waste hierarchy remains the cornerstone of most waste minimisation strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste; see: resource recovery. The waste hierarchy is represented as a pyramid because the basic premise is for policy to take action first and prevent the generation of waste. The next step or preferred action is to reduce the generation of waste i.e. by re-use. The next is recycling which would include composting. Following this step is material recovery and waste-to-energy. Energy can be recovered from processes i.e. landfill and combustion, at this level of the hierarchy. The final action is disposal, in landfills or through incineration without energy recovery. This last step is the final resort for waste which has not been prevented, diverted or recovered. The waste hierarchy represents the progression of a product or material through the sequential stages of the pyramid of waste management. The hierarchy represents the latter parts of the life-cycle for each product.

1. Recycling is the process of converting waste materials into new materials and objects. It is an alternative to "conventional" waste disposal that can save material and help lower greenhouse gas emissions (compared to plastic production, for example). Recycling can prevent the waste of potentially useful materials and reduce the consumption of fresh raw materials, thereby reducing: energy usage, air pollution (from incineration), and water pollution (from land filling).

Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, and Recycle" waste hierarchy.

There are some ISO standards related to recycling such as ISO 15270:2008 for plastics waste and ISO 14001:2004 for environmental management control of recycling practice.

Recyclable materials include many kinds of glass, paper, and cardboard, metal, plastic, tires, textiles, and electronics. The composting or other reuse of biodegradable waste—such as food or garden waste—is also considered recycling. Materials to be recycled are either brought to a collection centre or picked up from the curb side, then sorted, cleaned, and reprocessed into new materials destined for manufacturing.

In the strictest sense, recycling of a material would produce a fresh supply of the same material—for example, used office paper would be converted into new office paper or used polystyrene foam into new polystyrene. However, this is often difficult or too expensive (compared with producing the same product from raw materials or other sources), so "recycling" of many products or materials involves their *reuse* in producing different materials (for example, paperboard) instead. Another form of recycling is the salvage of certain materials from complex products, either due to their intrinsic value (such as lead from car batteries, or gold from circuit boards), or due to their hazardous nature (e.g., removal and reuse of mercury from thermometers and thermostats).

2. Reuse is the action or practice of using something again, whether for its original purpose (conventional reuse) or to fulfil a different function (creative reuse or repurposing). It should be distinguished from recycling, which is the breaking down of used items to make raw materials for the manufacture of new products. Reuse – by taking, but not reprocessing, previously used items – helps save time, money, energy, and resources. In broader economic terms, it can make quality products available to people and organizations with limited means, while generating jobs and business activity that contribute to the economy.

Historically, financial motivation was one of the main drivers of reuse. In the developing world this driver can lead to very high levels of reuse, however rising wages and consequent consumer demand for the convenience of disposable products has made the reuse of low value items such as packaging uneconomic in richer countries, leading to the demise of many reuse programs. Current environmental awareness is gradually changing attitudes and regulations, such as the new packaging regulations, are gradually beginning to reverse the situation.

One example of conventional reuse is the doorstep delivery of milk in refillable bottles; other examples include the retreading of tires and the use of returnable/reusable plastic boxes, shipping containers, instead of single-use corrugated fibre board boxes.

3. Waste minimization or Reduce: is a process of elimination that involves reducing the amount of waste produced in society and helps to eliminate the generation of harmful and persistent wastes, supporting the efforts to promote a more sustainable society. Waste minimisation involves redesigning products and/or changing societal patterns, concerning consumption and production, of waste generation, to prevent the creation of waste.

The most environmentally resourceful, economically efficient, and cost effective way to manage waste is to not have to address the problem in the first place. Waste minimisation should be seen as a primary focus for most waste management strategies. Proper waste management can require a significant amount of time and resources; therefore, it is important to understand the benefits of waste minimisation and how it can be implemented in all sectors of the economy, in an effective, safe and sustainable manner.

The basic concept behind waste management is the waste hierarchy, where the most effective approaches to managing waste are at the top. Waste management is in contrast to waste minimisation. Waste management focuses on processing waste after it is created, concentrating on re-use, recycling, and waste-to-energy conversion rather than eliminating the creation of waste in the initial phases of production. Waste minimisation involves efforts to minimize resource and energy use during manufacture. For the same commercial output, usually the less materials are used, the less waste is produced. Waste minimisation usually requires knowledge of the production process, cradle-to-grave analysis (the tracking of materials from their extraction to their return to earth) and detailed knowledge of the composition of the waste.

The main sources of waste vary from country to country. In the UK, most waste comes from the construction and demolition of buildings, followed by mining and quarrying, industry and commerce. Household waste constitutes a relatively small proportion of all waste. Reasons for the creation of waste sometimes include requirements in the supply chain. For example, a company handling a product may insist that it should be packaged using particular packing because it fits its packaging equipment.

4. Life-cycle of a product

The life-cycle begins with design, then proceeds through manufacture, distribution, use and then follows through the waste hierarchy's stages of reduce, reuse and recycle. Each of the above stages of the life-cycle offers opportunities for policy intervention, to rethink the need for the product, to redesign to minimize waste potential, to extend its use. The key behind the life-cycle of a product is to optimize the use of the world's limited resources by avoiding the unnecessary generation of waste.

5. Resource efficiency

Resource efficiency reflects the understanding that current, global, economic growth and development cannot be sustained with the current production and consumption patterns. Globally, we are extracting more resources to produce goods than the planet can replenish. Resource efficiency is the reduction of the environmental impact from the production and consumption of these goods, from final raw material extraction to last use and disposal. This process of resource efficiency can address sustainability.

6. Polluter pays principle

The Polluter pays principle is a principle where the polluting party pays for the impact caused to the environment. With respect to waste management, this generally refers to the requirement for a waste generator to pay for appropriate disposal of the unrecoverable material.

1. What is Recycling?

Recycling is the process of collecting, separating, processing, and selling recyclable materials so they can be turned into new products. Simply put, recycling is taking something old and worn-out and turning it into something new.

2. What are some items at your home that can be recycled?

There are many items in your home that can often be recycled in your community. These items include aluminium and steel cans, newspapers, corrugated boxes, telephone books, plastic and glass bottles, used motor oil, large appliances, rechargeable batteries, automotive batteries and tires, clothing, and yard and food waste.

3. What is made from recyclable materials?

- Aluminium cans are melted down and recycled into new aluminium cans and other products made of aluminium.
- Steel cans are melted down and recycled into new steel cans and other products made of steel.
- Newspapers and telephone books are ground up and made into newsprint, cereal boxes, cellulose insulation for keeping homes warm, paper egg cartons, and ceiling tiles.
- Corrugated boxes are ground up and made into more corrugated boxes. Glass bottles are crushed, melted and recycled into more glass bottles, or used along with sand and gravel in asphalt roads.
- Plastic bottles such as soft drink and water bottles are ground up, washed and melted to produce fiber for carpet and clothing. Plastic bottles such as milk, shampoo and detergent bottles are ground up, washed and melted to produce plastic parts for automobiles, plastic lumber and other plastic products. Used motor oil is generally burned for fuel as an alternative energy resource in industrial facilities.
- Automobile scrap tires are generally chipped and burned as a fuel in place of or in addition to coal.
- Scrap tires are also manufactured into numerous rubber products including rubber mats and rubber bumpers.
- Yard and food waste can be composted in your backyard. Since the compost contains plenty of nitrogen and other organic nutrients, it is great in gardens and flower beds.

4. Why is it so important to recycle?

Recycling is important for several reasons.

1) Recycling conserves natural resources. Some of these natural resources such as oil, natural gas and minerals are non-renewable resources. Simply put, they don't get replaced as we pull them out of the ground. Once they're gone, they're gone forever.

2) Recycling conserves landfill space. Landfill space will last longer if we only put items that are not recyclable into them. It costs a great deal of money to build a landfill and we need to be careful how much and how fast we fill them up.

3) Recycling employs people. Recycling employs people who a) collect the recyclable material, b) process the material or get it ready to sell to a manufacturer, c) transport the materials to factories where it will be turned into new products, d) take the material and manufacture it into new products, e) manufacture equipment and products used by the recycling industry, and f) manage local, state and federal government recycling programs and private and non-profit recycling programs.

4) Recycling conserves energy. Without question, recycling conserves the energy that would be necessary to create the same product from its raw resource.

5) Recycling reduces our dependence on overseas natural resources. This is important in two very important ways, a) it reduces our dependence on overseas oil and gas which has national security implications and b) it reduces our foreign trade deficit which is important to the strength of our economy.

5. What is waste management?

Waste management is the collection, transportation and disposal of waste materials.

6. What are the rules and regulations guiding waste management in India

Municipal Solid Waste (Management and Handling) Rules 2000 regulate the management and handling of the municipal solid wastes and are applicable to every municipal authority responsible for collection, segregation, storage, transportation, processing and disposal of municipal solid wastes

Bio-Medical Waste (Management and Handling) Rules, 1998 regulate the management and handling of bio-medical waste and are applicable to all persons who generate, collect, receive, store, transport, treat, dispose, or handle bio medical waste in any form.

E-Waste (Management and Handling) Rules, 2010 regulate the management and handling of electrical and electronic waste and is applicable to every producer, consumer involved in manufacture, sale, purchase and processing of these equipment or its components.

7. What are the common methods of waste disposal?

The commonly practiced technologies for SWM can be grouped under three major categories, i.e., bio-processing, thermal processing and sanitary landfill. The bio-processing method includes aerobic and anaerobic composting. Thermal methods are incineration and pyrolysis. Sanitary landfill is generally used to dispose of the final rejects coming out of the biological and thermal waste processing units.

a) **What is aerobic composting?**

Aerobic composting is the creation of fertilizing compost using bacteria that thrive in an oxygen-rich environment. Aerobic composting is considered the fastest method of composting, but involves more work in terms of rotating the organic material periodically.

b) **What is anaerobic composting?**

Anaerobic composting is the creation of fertilising compost using bacteria that cannot thrive in the presence of oxygen. Anaerobic composting is known to work slowly, but also requires lesser work.

c) **What is incineration?**

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration of waste materials converts the waste into ash, flue gas, and heat. In some cases, the heat generated by incineration can be used to generate electric power.

d) **What is a sanitary landfill?**

A sanitary landfill is a low-lying area that is filled with waste rejects. It has a liner at the bottom to prevent the groundwater from contaminating with the mix of the liquid that oozes from the waste that is buried called the leachate. Waste is buried in-between layers of soil and is compacted nicely to make it a hard surface. When the landfill is completed, it is capped with a layer of clay or a synthetic liner in order to prevent water from entering. A final topsoil cover is placed, compacted and graded, and various forms of vegetation may be planted in order to reclaim the otherwise useless land.

PRINCIPLES OF MUNICIPAL SOLID WASTE MANAGEMENT

Municipal Solid Waste Management involves the application of principle of Integrated Solid Waste Management (ISWM) to municipal waste. ISWM is the application of suitable techniques, technologies and management programs covering all types of solid wastes from all sources to achieve the twin objectives of (a) waste reduction and (b) effective management of waste still produced after waste reduction.

(a)Waste Reduction:

It is now well recognised that sustainable development can only be achieved if society in general, and industry in particular, produces ‘more with less’ i.e. more goods and services with less use of the world’s resources (raw materials and energy) and less pollution and waste. Production as well as product changes have been introduced in many countries, using internal recycling of materials or on-site energy recovery, as part of solid waste minimisation schemes.

(b) Effective Management of Solid Waste:

Effective solid management systems are needed to ensure better human health and safety. They must be safe for workers and safeguard public health by preventing the spread of disease. In addition to these prerequisites, an effective system of solid waste management must be both environmentally and economically sustainable.

• Environmentally sustainable: It must reduce, as much as possible, the environmental impacts of waste management.

• Economically sustainable: It must operate at a cost acceptable to community.

Clearly it is difficult to minimise the two variables, cost and environmental impact, simultaneously. There will always be a trade-off. The balance that needs to be struck is to reduce the overall environmental impacts of the waste management system as far as possible, within an acceptable level of cost.

An economically and environmentally sustainable solid waste management system is effective if it follows an integrated approach i.e. it deals with all types of solid waste materials and all sources of solid waste A multi-material, multi-source management approach is usually effective in environmental and economic terms than a material specific and source specific approach. Specific wastes should be dealt with in such a system but in separate streams   an effective waste management system includes one or more of the following options:

- Waste collection and transportation.
- Resource recovery through sorting and recycling i.e. recovery of materials (such as paper, glass, metals) etc. through separation.
- Resource recovery through waste processing i.e. recovery of materials (such as compost) or recovery of energy through biological, thermal or other processes.
- Waste transformation (without recovery of resources) i.e. reduction of volume, toxicity or other physical/chemical properties of waste to make it suitable for final disposal.
- Disposal on land i.e. environmentally safe and sustainable disposal in landfills.

Recycling: Recycling is a process by which waste is processed in some way to be reformed into new or similar products. The principle is to make a usable product from the waste. Plastic bottles, newspapers, cardboard and tin cans can all be reprocessed and made into new items. Plastic bags can also be recycled and used to make mats, carpets and other products. Waste metal has a number of possible uses because it is relatively easy to reshape (Figure1.0). Careful separation of the waste into its different types is important for the efficiency of recycling processes. Recycling not only reduces the quantity of waste but also saves money, so there is an economic, as well as an environmental, incentive to recycle.

Figure 1.0 Waste metal can be recycled by using it to make new and different products.

Q) Methods of solid waste disposal and management are as below:

1. Open burning
2. Dumping into the sea
3. Sanitary Landfills
4. Incineration
5. Composting
6. Ploughing in fields
7. Hog feeding
8. Grinding and discharging into sewers
9. Salvaging
10. Fermentation and biological digestion
11. pyrolisis

1. Open burning of Solid Wastes: Not an ideal method in the present day context

2. Dumping into the Sea:

- Possible only in coastal cities
- Refuse shall be taken in barges sufficiently far away from the coast (15-30 km) and dumped there
- Very costly
- Not environment friendly

3. Sanitary Land filling of Solid Wastes

- Simple, cheap, and effective
- A deep trench (3 to 5 m) is excavated
- Refuse is laid in layers
- Layers are compacted with some mechanical equipment and covered with earth, levelled, and compacted
- With time, the fill would settle
- Microorganisms act on the organic matter and degrade them
- Decomposition is similar to that in composting
- Facultative bacteria hydrolyze complex organic matter into simpler water soluble organics
- These diffuse through the soil where fungi and other bacteria convert them to carbon dioxide and water under aerobic conditions
- Aerobic methanogenic bacteria utilize the methane generated and the rest diffuses into the atmosphere
- Too much refuse shall not be buried – fire hazard
- Moisture content – not less than 60% for good biodegradation
- Refuse depth more than 3m – danger of combustion due to compression of bottom layers – hence should be avoided
- Refuse depth is generally limited to 2m
- Temperature in the initial stages of decomposition – as high as 70 degree C – then drops
- Reclaimed areas may be used for other uses

Engineered Landfills of Solid Wastes

- Bottom of the trench is lined with impervious material to prevent the leachate from contaminating groundwater
- A well designed and laid out leachate collection mechanism is to be provided
- Leachate so collected is treated and then disposed off

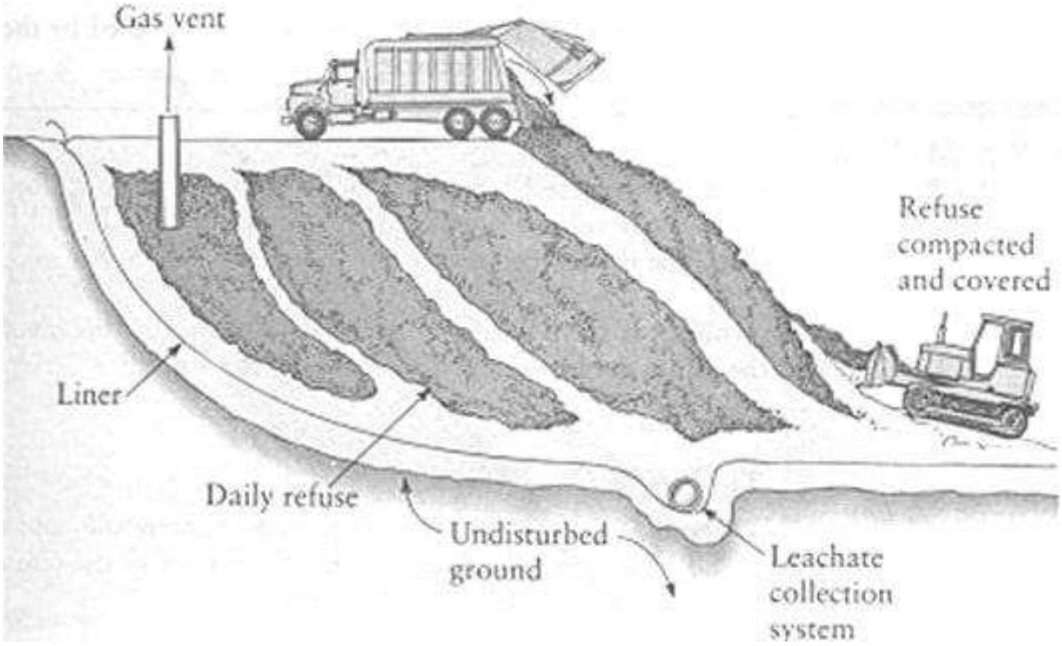
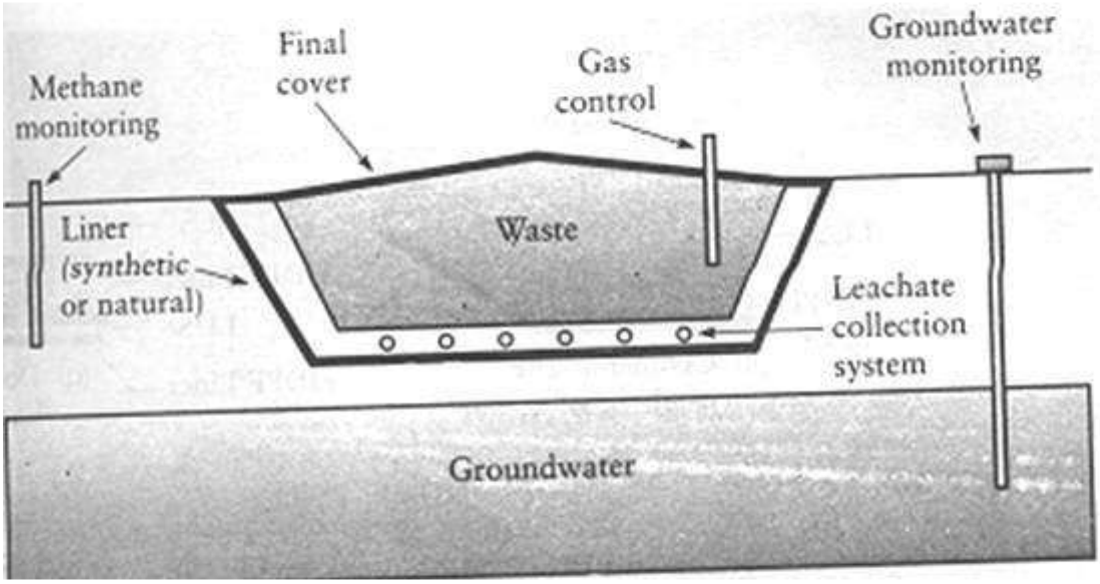


Figure: A Typical Sanitary Landfill for Solid Waste

Components of a Typical Landfill



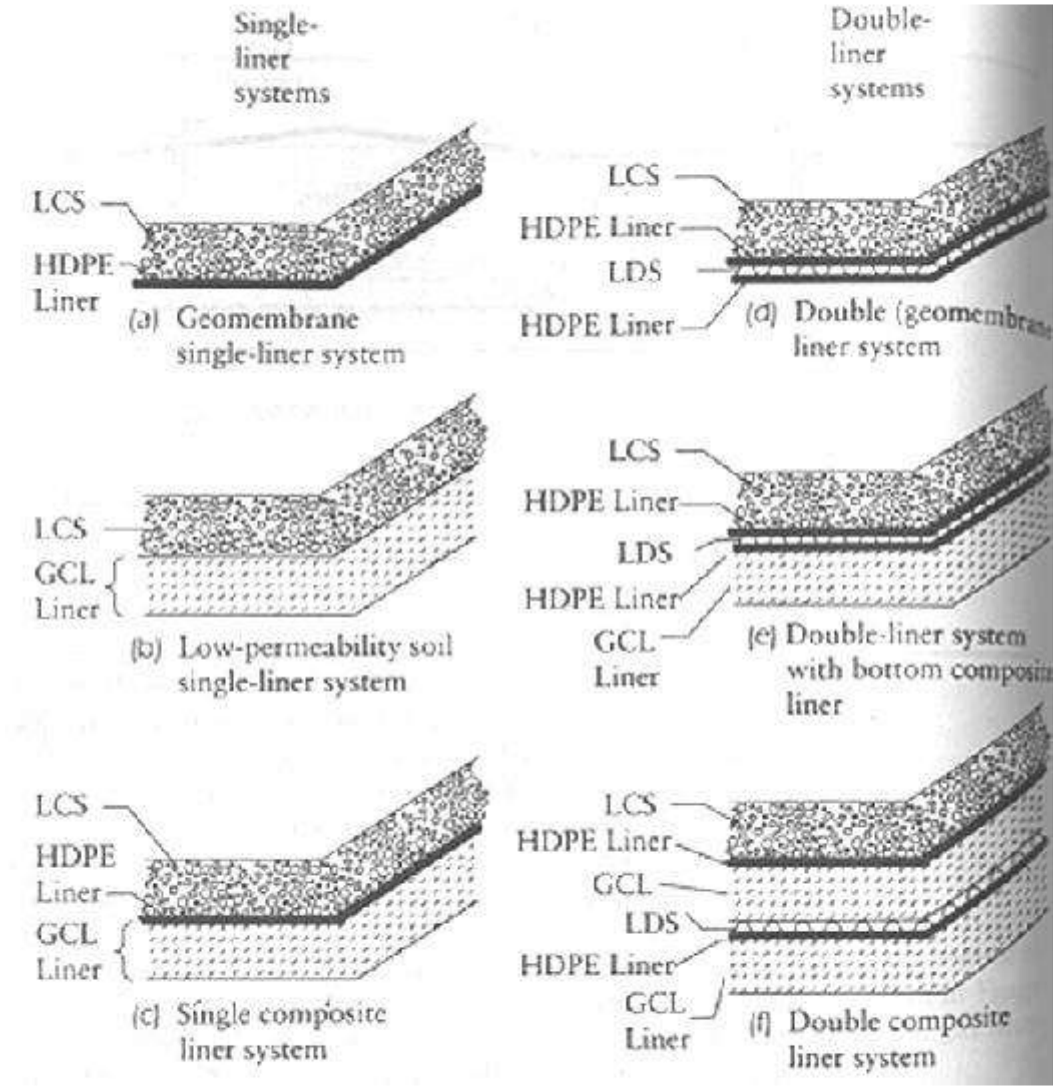


Figure: Examples of systems in municipal solid waste landfills

Where LCS = Leachate collection system

GCS = Geo synthetic clay liner

LDS = Leachate detection system

4. Incineration of Solid Waste

- A method suited for combustible refuse
- Refuse is burnt
- Suited in crowded cities where sites for land filling are not available
- High construction and operation costs
- Sometimes used to reduce the volume of solid wastes for land filling

- Primary chamber – designed to facilitate rapid desiccation of moist refuse and complete combustion of refuse and volatile gases
- A ledge or drying hearth is provided for this purpose
- Secondary chamber – between the primary chamber and the stack – temperatures above 700 degree C
- All unburnt and semi burnt material are completely burnt here

a).Waste to Energy Combustors

- Incinerators – Refuse was burned without recovering energy – exhaust gas is very hot – exceeds the acceptable inlet temperature for electrostatic precipitators used for particulate emission control
- Modern combustors – combine solid waste combustion with energy recovery

b).Combustors for Solid Waste

- Storage pit – for storing and sorting incoming refuse
- Crane – for charging the combustion box
- Combustion chamber consisting of bottom grates on which combustion occurs
- Grates on which refuse moves
- Heat recovery system of pipes in which water is turned to steam.
- Ash handling systems
- Air pollution control systems
- Grates – Provide turbulence so that the MSW can be thoroughly burned, moves the refuse down, provides under fire air to the refuse through openings in it (to assist in combustion as well as to cool the grates)
- Operating temperature of combustors ~ 980 to 1090 degree C

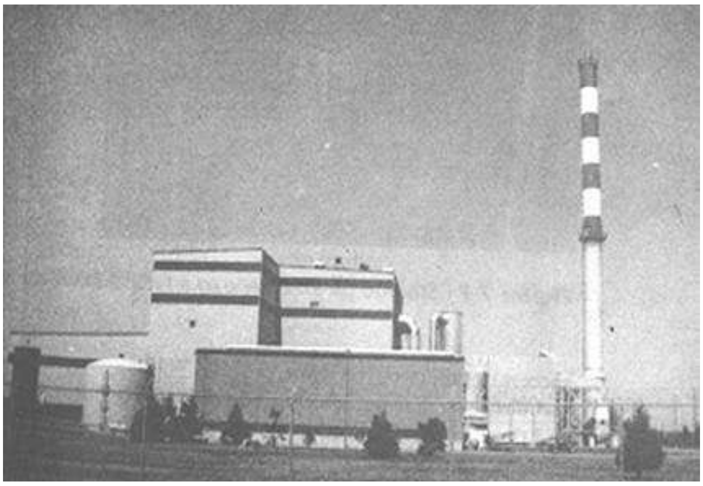


Figure: A typical MSW Combustor

Grates of MSW Combustor

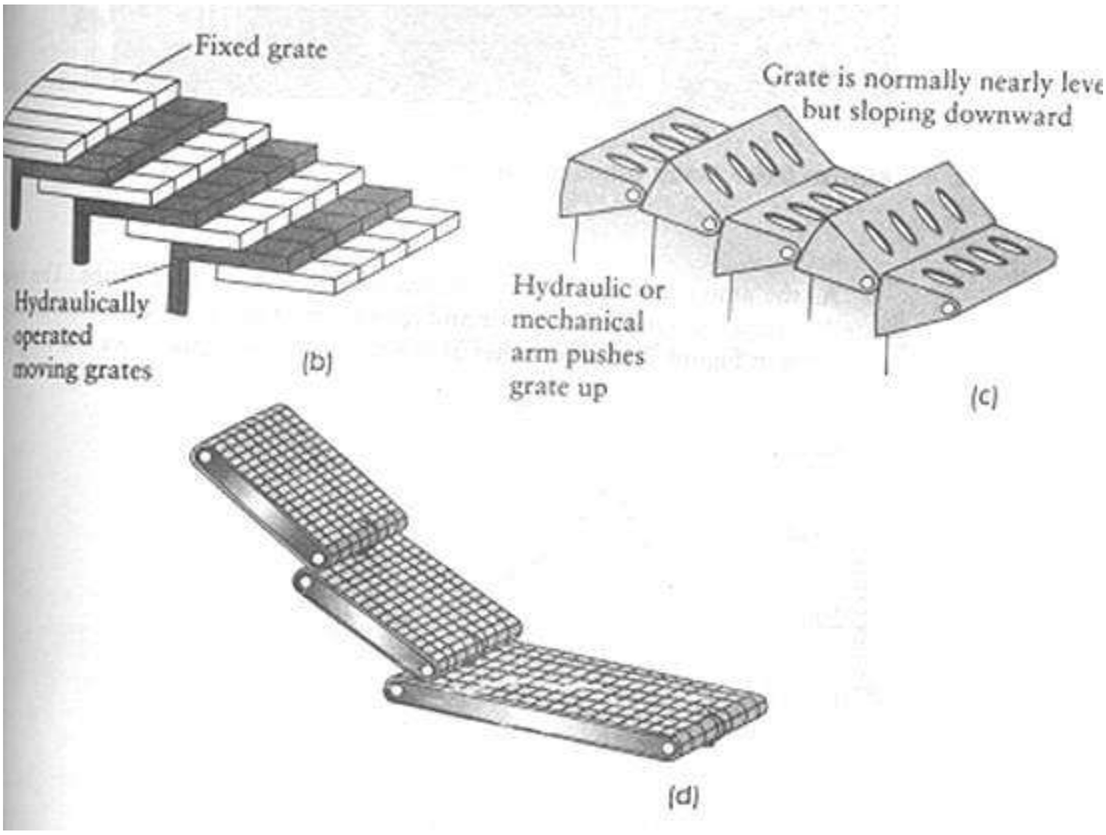


Figure: Grates of MSW combustor. The under fire air is blown through the holes in the drawings show three types grates. (a) Reciprocating (b) Rocking (c) Travelling

5. Composting:

- Similar to sanitary land filling
- Yields a stable end product – good soil conditioner and may be used as a base for fertilizers
- Popular in developing countries
- Decomposable organic matter is separated and composted

Methods of composting:

a) Open window composting

b) Mechanical composting

a) Open window composting:

- Refuse is placed in piles, about 1.5m high and 2.5m wide at about 60% moisture content

- Heat build-up in the refuse piles due to biological activity – temperature rises to about 70 degree C
- Pile is turned up for cooling and aeration to avoid anaerobic conditions
- Moisture content is adjusted to about 60%
- Piled again – temperature rises to about 70 degree C
- The above operations are repeated
- After a few days (~ 7 to 10 weeks) temperature drops to atmospheric temperature – indication of stabilization of compost

b) Mechanical composting:

- Process of stabilization is expedited by mechanical devices of turning the compost
- Compost is stabilized in about 1 to 2 weeks
- To enrich compost – night soil, cow dung etc. are added to the refuse
- Usually done in compost pits
- Arrangements for draining of excess moisture are provided at the base of the pit
- At the bottom of the pit, a layer of ash, ground limestone, or loamy soil is placed – to neutralize acidity in the compost material and providing an alkaline medium for microorganisms
- The pit is filled by alternate layers of refuse (laid in layers of depth 30 – 40 cm) and night soil or cow dung (laid over it in a thin layer)
- Material is turned every 5 days or so After ~ 30 days – it is ready for use.

c) Vermi composting:

Ideal for biodegradable wastes from kitchens, hotels etc. At household level, a vessel or tray more than 45 cm deep, and 1 x 0.60m may be sufficient A hole shall be provided at one end in the bottom for draining the leachate out into a tray or vessel Lay 1" thick layer of baby metal or gravel at the bottom of the tray Above that lay an old gunny bag or a piece of thick cloth, a layer of coconut husk upside down over it and above that a 2" thick layer of dry leaves and dry cow dung (powdered)Lay the biodegradable waste over it. Introduce good quality earthworms into it (~ 10 g for 0.6 x 0.45 x 0.45 m box). If the waste is dry, sprinkle water over it daily Rainwater should not fall into the tray or vessel or box Keep it closed. If the box is kept under bright sun earthworms will go down and compost can be taken from the top Compost can be dried and stored Continue putting waste into the box Add little cow dung at intervals. Do not use vermin wash directly. Dilute in the ratio 1:10 before use.

Other composting Methods used in India:

Indore method – aerobic – brick pits 3 x 3 x 1 m – up to 8-12 weeks materials are turned regularly in the pits and then kept on ground for about 4-6 weeks – 6 to 8 turnings in total

Bangalore method – anaerobic – earthen trenches 10 x 1.5 x 1.5 m – left for decomposition – takes 4 to 5 months

6) .Disposal by Ploughing into fields

- Not very commonly used
- Not environment friendly in general

7). Disposal by hog feeding:

- Not common in India
- Refuse is ground well in grinders and then fed into sewers
- Disposal of garbage into sewers – BOD and TSS increases by 20-30%
- Disposal of residual refuse – still a problem

8. Salvaging:

- Materials like paper, metal, glass, rags, certain types of plastic etc. can be salvaged, recycled, and reused

9. Fermentation or Biological Digestion:

- Biodegradable Waste – convert to compost
- Recycle whatever is possible
- Hazardous wastes – dispose it by suitable methods
- Landfill or incinerate the rest

10. Pyrolysis:

Pyrolysis is a form of incineration that chemically decomposes organic materials by heat in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above 430 °C (800 °F).

In practice, it is not possible to achieve a completely oxygen-free atmosphere. Because some oxygen is present in any pyrolysis system, a small amount of oxidation occurs. If volatile or semi-volatile materials are present in the waste, thermal desorption will also occur.

Organic materials are transformed into gases, small quantities of liquid, and a solid residue containing carbon and ash. The off-gases may also be treated in a secondary thermal oxidation unit. Particulate removal equipment is also required. Several types of pyrolysis units are available, including the rotary kiln, rotary hearth furnace, and fluidized bed furnace. These units are similar to incinerators except that they operate at lower temperatures and with less air supply.

Benefits of Composting:

As of 2013, over 27% of all municipal solid waste in the United States was comprised of yard and food waste. By composting these items, it makes it possible to reduce the overall amount of waste being sent to landfills and mass-burn incinerators.

In addition to reducing waste, the process of composting also creates a usable product. The final compost, humus, is nutrient-rich and can be used to amend poor soils and fertilize gardens instead of using chemical fertilizers. The added compost also helps soil retain water and therefore can improve growing conditions.

Composting Basics:

There are five main areas that must be “controlled” during composting.

1. Feedstock and Nutrient Balance

Composting, or controlled decomposition, requires a proper balance of “green” organic materials and “brown” organic materials. “Green” organic material includes grass clippings, food scraps, and manure, which contain large amounts of nitrogen. “Brown” organic materials include dry leaves, wood chips, and branches, which contain large amounts of carbon but little nitrogen. Obtaining the right nutrient mix requires experimentation and patience. It is part of the art and science of composting.

2. Particle Size

Grinding, chipping, and shredding materials increases the surface area on which microorganisms can feed. Smaller particles also produce a more homogeneous compost mixture and improve pile insulation to help maintain optimum temperatures (see below). If the particles are too small, however, they might prevent air from flowing freely through the pile.

3. Moisture Content

Microorganisms living in a compost pile need enough moisture to survive. Water is the key element that helps transports substances within the compost pile and makes the nutrients in organic material accessible to the microbes. Organic material contains some moisture in varying amounts, but moisture also might come in the form of rainfall or intentional watering.

4. Oxygen Flow

Turning the pile, placing the pile on a series of pipes, or including bulking agents such as wood chips and shredded newspaper all help aerate the pile. Aerating the pile allows decomposition to occur at a faster rate than anaerobic conditions. Care must be taken, however, not to provide too much oxygen, which can dry out the pile and impede the composting process.

5. Temperature

Microorganisms require a certain temperature range for optimal activity. Certain temperatures promote rapid composting and destroy pathogens and weed seeds. Microbial activity can raise the temperature of the pile's core to at least 140° F. If the temperature does not increase, anaerobic conditions (i.e., rotting) occur. Controlling the previous four factors can bring about the proper temperature.

METHOD OF COMPOSTING:

1. On-site Composting

2. Vermi composting

3. Aerated (Turned) Windrow Composting

4. Aerated Static Pile Composting

5. In-Vessel Composting

1. Onsite Composting

Organizations that are going to compost small amounts of wasted food can compost onsite. Composting can significantly reduce the amount of wasted food that is thrown away. Yard trimmings and small quantities of food scraps can be composted onsite. Animal products and large quantities of food scraps are not appropriate for onsite composting.

- The climate and seasons changes will not have a big effect on onsite composting. Small adjustments can be made when changes happen such as when the rainy season approaches.
- Food scraps need to be handled properly so they don't cause odours or attract unwanted insects or animals.
- Onsite composting takes very little time or equipment. Education is the key. Local communities might hold composting demonstrations and seminars to encourage homeowners or businesses to compost on their own properties.
- Creating compost can take up to two years, but manual turning can speed up the process to between three to six months.
- Compost, however, should not be used as potting soil for houseplants because of the presence of weed and grass seeds.
- You can leave grass clippings on the lawn-known as "grass cycling." These cuttings will decompose naturally and return some nutrients back to the soil, similar to composting.
- You can put leaves aside and use them as mulch around trees and scrubs to retain moisture.

2. Vermi composting

Red worms in bins feed on food scraps, yard trimmings, and other organic matter to create compost. The worms break down this material into high quality compost called castings. Worm bins are easy to construct and are also available for purchase. One pound of mature worms (approximately 800-1,000 worms) can eat up to half a pound of organic material per day. The bins can be sized to match the volume of food scraps that will be turned into castings.

It typically takes three to four months to produce usable castings. The castings can be used as potting soil. The other by product of vermin composting known as “worm tea” is used as a high-quality liquid fertilizer for houseplants or gardens.

What Can Be Composted – Vermiculture?

- Food scraps
- Paper
- Yard trimmings such as grass and plants
- Ideal for apartment dwellers or small offices.
- Schools can use vermin culture to teach children conservation and recycling.
- It is important to keep the worms alive and healthy by providing the proper conditions and sufficient food.
- Prepare bedding; bury garbage, and separate worms from their castings.
- Worms are sensitive to changes in climate.
- Extreme temperatures and direct sunlight are not healthy for the worms.
- The best temperatures for vermin composting range from 55° F to 77° F.
- In hot, arid areas, the bin should be placed under the shade.
- Vermi composting indoors can avoid many of these problems.

3. Aerated (Turned) Windrow Composting

Aerated or turned windrow composting is suited for large volumes such as that generated by entire communities and collected by local governments, and high volume food-processing businesses (e.g., restaurants, cafeterias, packing plants). It will yield significant amounts of compost, which might require assistance to market the end-product. Local governments may want to make the compost available to residents for a low or no cost.

This type of composting involves forming organic waste into rows of long piles called “windrows” and aerating them periodically by either manually or mechanically turning the piles. The ideal pile height is between four and eight feet with a width of 14 to 16 feet. This size pile is large enough to generate enough heat and maintain temperatures. It is small enough to allow oxygen flow to the windrow's core.

Large volumes of diverse wastes such as yard trimmings, grease, liquids, and animal by-products (such as fish and poultry wastes) can be composted through this method.

- Windrow composting often requires large tracts of land, sturdy equipment, a continual supply of labour to maintain and operate the facility, and patience to experiment with various materials mixtures and turning frequencies.
- In a warm, arid climate, windrows are sometimes covered or placed under a shelter to prevent water from evaporating.
- In rainy seasons, the shapes of the pile can be adjusted so that water runs off the top of the pile rather than being absorbed into the pile.
- Windrow composting can work in cold climates. Often the outside of the pile might freeze, but in its core, a windrow can reach 140° F.
- Leachate is liquid released during the composting process. This can contaminate local ground water and surface-water supplies. It should be collected and treated.
- Windrow composting is a large-scale operation and might be subject to regulatory enforcement, zoning, and sitting requirements. Compost should be tested in a laboratory for bacterial and heavy metal content.
- Odours also need to be controlled. The public should be informed of the operation and have a method to address any complaints about animals or bad odours.

4. Aerated Static Pile Composting

Aerated static pile composting produces compost relatively quickly (within three to six months). It is suitable for a relatively homogenous mix of organic waste and work well for larger quantity generators of yard trimmings and compostable municipal solid waste (e.g., food scraps, paper products), such as local governments, landscapers, or farms. This method, however, does not work well for composting animal by-products or grease from food processing industries.

In aerated static pile composting, organic waste mixed in a large pile. To aerate the pile, layers of loosely piled bulking agents (e.g., wood chips, shredded newspaper) are added so that air can pass from the bottom to the top of the pile. The piles also can be placed over a network of pipes that deliver air into or draw air out of the pile. Air blowers might be activated by a timer or a temperature sensors.

- In a warm, arid climate, it may be necessary to cover the pile or place it under a shelter to prevent water from evaporating.
- In the cold, the core of the pile will retain its warm temperature. Aeration might be more difficult because passive air flowing is used rather than active turning. Placing the aerated static piles indoors with proper ventilation is also sometimes an option.
- Since there is no physical turning, this method requires careful monitoring to ensure that the outside of the pile heats up as much as the core.

- Applying a thick layer of finished compost over the pile may help alleviate any odors. If the air blower draws air out of the pile, filtering the air through a bio filter made from finished compost will also reduce any of the odours.
- This method may require significant cost and technical assistance to purchase, install, and maintain equipment such as blowers, pipes, sensors, and fans.
- Having a controlled supply of air allows construction of large piles, which require less land than the windrow method.

5. In-Vessel Composting

In-vessel composting can process large amounts of waste without taking up as much space as the windrow method and it can accommodate virtually any type of organic waste (e.g., meat, animal manure, bio solids, food scraps). This method involves feeding organic materials into a drum, silo, concrete-lined trench, or similar equipment. This allows good control of the environmental conditions such as temperature, moisture, and airflow. The material is mechanically turned or mixed to make sure the material is aerated. The size of the vessel can vary in size and capacity.

This method produces compost in just a few weeks. It takes a few more weeks or months until it is ready to use because the microbial activity needs to balance and the pile needs to cool.

- Some are small enough to fit in a school or restaurant kitchen.
- Some are very large, similar to the size of school bus. Large food processing plants often use these.
- Careful control, often electronically, of the climate allows year-round use of this method.
- Use in extremely cold weather is possible with insulation or indoor use.
- Very little odour or leachate is produced.
- This method is expensive and may require technical expertise to operate it properly.
- Uses much less land and manual labour than windrow composting.

ADVANTAGES OF COMPOSTING:

There are a lot of advantages in using homemade fertilizers on your garden. It is practically free, since you are re-using materials that you already used or recycling materials that you don’t need any longer. You can also get these materials for free from family and friends or neighbours or even in bags on the street when people put out yard clippings and leaves in trash bags on the street to be collected. You can also sometimes get manure from local farmers for free, or for very low cost if they deliver it to your home.

Preparing your own fertilizer is very environmentally friendly and a lot of people are trying to do more to help the environment these days. If you want to garden in an eco-friendly way that reduces your footprint on the planet, natural homemade fertilizers are a great way in producing and providing the needs of your garden.

ADVANTAGES OF INCINERATION:

1. Incineration causes a significant reduction in the volume of waste. The reduction in the original volume and weight 95% and 75% respectively.
2. It helps providing a renewable source and conserving valuable raw materials.
3. Bottom ash can be reused – as secondary aggregates for parking lots, paved roads etc.
4. Due to incineration, a large proportion of the organic compounds including putresible and hazardous waste is destroyed. So there is a net reduction in the quantity of toxicity.
5. Incineration does not does not generate methane gas and reduces methane from landfills.
6. It provides better control over odour and noise.
7. It occupies small land

DISADVANTAGES OF INCINERATION:

The disadvantages of incineration are as follows.

1. It causes atmospheric pollution if incinerators are not ell maintained.
2. Incinerators are costly to construct, operate and regulate. Stringent emission for incinerators increases the cost of construction, operation and maintenance.
3. It lacks system flexibility. The demand for recycled and recovered material for different treatment methods is likely to change overtime.
4. Incineration process produces ash and waste water from pollution control devices.
5. A huge amount of money required to purchase a foreign made incinerator.
6. Low income countries often lacks of adequately trained labour to operate and maintain incinerator systems.

UNIT –VI

NOISE POLLUTION AND CONTROL

Syllabus: Sources of noise pollution, Impacts of noise pollution, Measurements and permissible limits of noise, Control methods of noise pollution, the noise pollution (Regulation and control) rules, 2000 as per CPCB

DEFINITION: Sound, a normal feature of our life, is the means of communication and entertainment in most animals, including human beings. It is also a very effective alarm system. A low sound is pleasant whereas a loud sound is unpleasant and is commonly referred to as 'noise'. Noise can be defined as an unpleasant and unwanted sound.

Whether a given sound is as pleasant as music (or) as unpleasant as noise depends on its loudness, duration, rhythm and the mood of the person. But loudness is definitely the most significant criterion which converts sound into noise. Exposure to loud noise is indeed annoying and harmful too.

Noise is a physical form of pollution and is not directly harmful to the life supporting systems namely air, soil and water. Its effects are more directly on the receiver i.e. man. Noise pollution is the result of modern industrialized urban life and congestion due to over population.

Even though noise pollution is not fatal to human life, yet its importance cannot be overlooked because repeated exposure to noise reduces the sleeping hours and productivity or efficiency of a human being. It affects the peace of mind and invades the privacy of a human being. The importance of noise pollution as environmental problem is being recognised as the ill effects of noise on human health and environment are becoming evident with each passing day.

Sources of Noise Pollution:

The sources of noise pollution are classified into two broad categories: Internal and external sources of noise pollution.

External sources of Noise:

These are the major sources of noise pollution in the environment. They are sources that are extremely difficult to control. They include.

- **Industrial sources.** The industrialization has resulted in the rise of noise pollution. The industries include textile mills, engineering plants, printing presses, and metal industries. Most industries use heavy machines capable of producing very high levels of noise. They have equipment such as compressors, exhaust fans, grinding mills, and generators which increase the overall noise levels in the environment. Workers in these environments are in great health risks in case they do not take proper measures like wearing earplugs to minimize the effect of the noise.

- **Vehicles for transportation.** Automobile revolution has turned out to be a big source of environmental noise in urban regions. In the modern age, there is an increase in traffic due to the growth in the number of vehicles such as buses, trains, and trucks. People caught in traffic jams are also often impatient and will continuously hoot their horns in an attempt to alert the driver in front of them to move. These acts produce unbearable noise to the people living in the neighboring areas, the commuters or passersby, and the environment as a whole. Airplanes also increase the problem of noise in major urban cities. Most airports are located near residential areas and for this reason, the jet-planes taking off and landing in such areas normally produce high sound levels.

- **Poor urban planning**. Developing nations habitually lack proper urban planning that leads to congested housing, small spaces, small industry proliferation, and lack of enough parking areas. Poor urban planning thus contributes to environmental noise through fights or social and basic amenities, noise from small manufacturing industries, wrangles over parking space, family quarrels from the neighboring houses, and noise from playing children.

- **Public address systems**. Public functions such as rallies, strikes, elections, religious and secular events use addressing systems that are very loud. The organizers of such events normally flout the rules set against public noise pollution by the state. Loud noise from public address systems and music systems during social events such as parties and religious crusades are another source of noise pollution. Open markets also often produce high levels of noise pollution due to the activities of buying and selling, and the use of loudspeakers and megaphones in advertising merchandise or services.

- **Agriculture machines**. Noise level of as high as 90 dB to 98 dB has been recorded in some farms using heavy types of machinery and equipment. This equipment includes thrashers, tube wells, tractors, drillers, powered tillers, and harvesters.

- **Military equipment**. Artillery tanks, rocket launching, military airplanes drills, explosions, and shooting practice are serious noise polluters. Deafening impacts are produced by the sounds of jet engines and in extreme cases, they cause the shattering of window panes and cracking of old dilapidates buildings located near their take-off and landing areas or when they fly past such structures.

Indoor sources of Noise:

They are noises associated with human activities within a household or building. They also occur due to operations of building services and office services.

- **Inside building services.** Construction works, workshops and automobile repairs cause noise pollution. The equipment used in such jobs produces a lot of noise that causes nuisance and may hamper hearing ability.

- **Household activities**. These are activities such as the loud banging of doors, noises from playing children, furniture movement, crying infants, loud arguments. Many households also own entertainment equipment such as Hi-Fi Systems, Television sets, and loudspeakers that may further contribute to the overall noise emanating from indoor household activities. Household equipment like pressure cookers, vacuum cleaners, washing machines, sewing machines, mix-grinders, desert coolers, exhaust fans, and air-conditioners equally produce a lot of noise.

- **Office equipment**. In offices, there are printers, photocopiers, and typewriters among other equipment that contribute to noise pollution in the working places and its environs.

Tips to control noise pollution

Some of the tips that can assist in controlling noise pollution include

- **Use of earplugs**. One of the cost-effective tips for reducing noise pollution is wearing earplugs. They can be worn in working places and while sleeping to reduce the amount of noise from the surrounding environment. They have health benefits such as healthy sleeping habits and prevent damage to the eardrum.

- **Soundproofing**. Industrial plants that produce a lot of noise from their machinery can use soundproof materials to reduce high sound frequencies. At home, one can install soundproofing materials which block the noise and associated vibrations. Double-pane windows, for example, can be an impressive method for preventing noise pollution.

- **Closing the windows**. To prevent unwanted noise from entering into the house and buildings, one can simply close the windows and open them when it is quite.

- **Jarring horns.** To reduce the noise that is associated with continuous hoots in traffic, vehicles can install horns that have jarring sounds. In cases where the exhaust pipes are damaged, they should be repaired and noisy trucks banned.

- **Law enforcement.** The state and local government should have proper laws that prevent noise pollution near residential areas. They can give authority to community law enforcers who will have the mandate of checking noise polluters. An example is whereby laws are enforced such that industries or noise-producing businesses are set up and operated away from schools, colleges, hospitals, and residential areas.

- **Noise-canceling headphones**. They can be used by workers to reduce noise pollution in industrial and construction workers. They filter any unwanted noise and prevent it from reaching the ears.

- **Use of barriers or go green by** planting trees. A simple way of reducing the vibrations and strong sound waves is through the use of barriers such as fences and planting trees around the house. These barriers would absorb the waves and reduce environmental noise significantly.

- **Lubrication and better maintenance of machines**. When the moving parts of machines and engines are well maintained and lubricated, it not only improves efficiency but also aids in reducing noise. The reason is that lubrication and proper maintenance reduces friction between moving parts.

- **The use of creativity in house and office layout**. Being innovative in the placement of equipment can significantly help in reducing noise pollution. Noisy house appliances and office equipment can be placed at the far ends of the house or office, therefore, reducing the levels of noise that reaches resting or working areas.

Effects of Noise Pollution

1. Hearing Problems

Any unwanted sound that our ears have not been built to filter can cause problems within the body. Our ears can take in a certain range of sounds without getting damaged. Man-made noises such as jackhammers, horns, machinery, airplanes and even vehicles can be too loud for our hearing range. Constant exposure to loud levels of noise can easily result in the damage of our eardrums and loss of hearing. It also reduces our sensitivity to sounds that our ears pick up unconsciously to regulate our body’s rhythm.

2. Health Issues

Excessive noise pollution in working areas such as offices, construction sites, bars and even in our homes can influence psychological health. Studies show that the occurrence of aggressive behavior, disturbance of sleep, constant stress, fatigue, and hypertension can be linked to excessive noise levels. These, in turn, can cause more severe and chronic health issues later in life.

3. Sleeping Disorders

Loud noise can certainly hamper your sleeping pattern and may lead to irritation and uncomfortable situations. Without a good night sleep, it may lead to problems related to fatigue and your performance may go down in the office as well as at home. It is therefore recommended to take a sound sleep to give your body proper rest.

4. Cardiovascular Issues

Blood pressure levels, cardiovascular disease, and stress-related heart problems are on the rise. Studies suggest that high-intensity noise causes high blood pressure and increases heartbeat rate as it disrupts the normal blood flow. Bringing them to a manageable level depends on our understanding of noise pollution and how we tackle it.

5. Trouble Communicating

High decibel noise can put trouble and may not allow two people to communicate freely. This may lead to misunderstanding and you may get difficult understanding the other person. Constant sharp noise can give you a severe headache and disturb your emotional balance.

6. Effect on Wildlife

Wildlife faces far more problems than humans because of noise pollution since they are more dependent on sound. Animals develop a better sense of hearing than us since their survival depends on it. The ill effects of excessive noise begin at home. Pets react more aggressively in households where there is a constant noise.

They become disoriented more easily and face many behavioural problems. In nature, animals may suffer from hearing loss, which makes them easy prey and leads to dwindling populations. Others become inefficient at hunting, disturbing the balance of the eco-system.

Species that depend on mating calls to reproduce are often unable to hear these calls due to excessive man-made noise. As a result, they are unable to reproduce and cause declining populations. Others require sound waves to echolocate and find their way when migrating. Disturbing their sound signals means they get lost easily and do not migrate when they should. To cope up with the increasing sound around them, animals are becoming louder, which may further add to the pollution levels. This is why understanding noise pollution can help us lower the impact it has on the environment.

As of now, there do not exist many solutions to reduce sound pollution. On a personal level, everybody can help to reduce the noise in their homes by lowering the volume of the radio, music system and the television. Listening to music without headphones is also a good step forward. Removal of public loudspeakers is another way in which pollution can be countered.

As is controlling the sound levels in clubs, bars, parties, and discos. Better urban planning can help in creating ‘No-Noise’ zones, where honking and industrial noise are not tolerated. It is only when our understanding of noise pollution is complete, can we take steps to eradicate it completely.

Permissible Noise Level in India

CPCB has laid down the permissible noise level in India for different areas. In industrial areas, the permissible limit is 75 dB for daytime and 70 dB at night. In commercial areas, it is 65 dB and 55 dB while in residential areas it is 55 dB and 45 dB during daytime and night respectively. Additionally, there is a category called 'silent zone' which includes areas that lie within 100 meters of the premises of schools, colleges, hospitals.

Area/ Zone	Category of Area / Zone	Limits in dB(A) Leq Day Time (from 6.00 a.m. to 10.00 p.m.)	Limits in dB(A) Leq Night Time (from 10.00 p.m. to 6.00 a.m.)
(A)	Industrial Area	75	70
(B)	Commercial Area	65	55
(C)	Residential Area	55	45
(D)	Silence Zone	50	40

The noise pollution (Regulation and control) rules, 2000 as per CPCB

1. **Short-title and commencement.**

    (1) These rules may be called the-Noise Pollution (Regulation and Control) Rules, 2000.

    (2) They shall come into force on the date of their publication in the Official Gazette.

2. **Definitions.-** In these rules, unless the context otherwise requires,

    (a) "Act" means the Environment (Protection) Act, 1986 (29 of 1986);

(b) "area/zone" means all areas which fall in either of the four categories given in the Schedule annexed to these rules;

(c) "authority" means any authority or officer authorised by the Central Government, or as the case may be, the State Government in accordance with the laws in force and includes a District Magistrate, Police Commissioner, or any other officer designated for the maintenance of the ambient air quality standards in respect of noise under any law for the time being in force;

(d) "person" in relation to any factory or premises means a person or occupier or his agent, who has control over the affairs of the factory or premises;

(e) "State Government" in relation to a Union territory means the Administrator thereof appointed under article 239 of the Constitution.

3. <u>Ambient air quality standards in respect of noise for different areas/zones.</u>

(1) The ambient air quality standards in respect of noise for different areas/zones shall be such as specified in the Schedule annexed to these rules.

(2) The State Government may categorize the areas into industrial, commercial, residential or silence areas/zones for the purpose of implementation of noise standards for different areas.

(3) The State Government shall take measures for abatement of noise including noise emanating from vehicular movements and ensure that the existing noise levels do not exceed the ambient air quality standards specified under these rules.

(4) All development authorities, local bodies and other concerned authorities while planning developmental activity or carrying out functions relating to town and country planning shall take into consideration all aspects of noise pollution as a parameter of quality of life to avoid noise menace and to achieve the objective of maintaining the ambient air quality standards in respect of noise.

(5) An area comprising not less than 100metres around hospitals, educational institutions and courts may be declared as silence area/zone for the purpose of these rules.

4. <u>Responsibility as to enforcement of noise pollution control measures.</u>

(1) The noise levels in any area/zone shall not exceed the ambient air quality standards in respect of noise as specified in the Schedule.

(2) The authority shall be responsible for the enforcement of noise pollution control measures and the due compliance of the ambient air quality standards in respect of noise.

5. <u>Restrictions on the use</u> of <u>loud speakers/public address s1stem.</u>

(1) A loud speaker or a public address system shall not be used except after obtaining written permission from the authority.

(2) A loud speaker or a public address system shall not be used at night (between 10.00 p.m. to 6.00 a.m.) Except in closed premises for communication within, e.g. auditoria, conference rooms, community halls and banquet halls.

6. <u>Consequences of any violation in silence zone/area.</u>

Whoever, in any place covered under the silence zone/area commits any of the following offence; he shall be liable for penalty under the provisions of the Act:

(i) whoever, plays any music or uses any sound amplifiers,

(ii) whoever, beats a drum or tom-tom or blows a horn either musical or pressure, or trumpet or beats or sounds any instrument, or

(iii) Whoever exhibits any mimetic, musical or other performances of a nature to 44raq crowds?

7. <u>Complaints to be made to the authority.</u>

(1) A person may, if the noise level exceeds the ambient noise standards by 10 dB (A) or more given in the corresponding columns against any area/zone, make a complaint to the authority.

(2) The authority shall act on the complaint and take action against the violator in accordance with the provisions of these rules and any other law in force.

8. <u>Power to prohibit etc. continuance of music sound or</u> noise.

(1) If the authority is satisfied from the report of an officer in charge of a police station or other information received by him that it is necessary to do so in order to prevent annoyance, disturbance, discomfort or injury or risk of annoyance, disturbance, discomfort or injury to the public or to any person who dwell or occupy property on the vicinity, he may, by a written order issue such directions as he may consider necessary to any person for preventing, prohibiting, controlling or regulating:

(a) the incidence or continuance in or upon any premises of -

(i) any vocal or instrumental music,

(ii) sounds caused by playing, beating, clashing, blowing or use in any manner whatsoever of any instrument including loudspeakers, public address systems, appliance or apparatus or contrivance which is capable of producing or re-producing sound, or

(b) The carrying on in or upon, any premises of any trade, avocation or operation or process resulting in or attended with noise.

(2) The authority empowered under sub-rule (1) may, either on its own motion, or on the application of any person aggrieved by an order made under sub-rule (1), either rescind, modify or alter any such order:

Provided that before any such application is disposed of, the said authority shall afford to the applicant an opportunity of appearing before it either in person or by a person representing him and showing cause against the order and shall, if it rejects any such application either wholly or in part, record its reasons for such rejection.