Uttar Pradesh Rajarshi Tandon Open University

M.Sc.

Environmental Science

PGEVS-102 (N)

Environmental Chemistry

COURSE INTRODUCTION

The objective of this course is to provide knowledge of environmental chemistry. The environmental chemistry deals with the chemical phenomenon in environment. The chemistry of air, water and soil are briefly described. In addition the analysis of environmental sample, its characterization techniques are mentioned. In this course chemistry behind major environmental issues, such as ozone depletion, global warming, acid rain, and the presence of toxic substances are discussed. Analyze the impact of human activities on the environment and the role of chemistry in mitigating and preventing environmental damage. Learn about environmental analytical techniques used to monitor pollutants, assess environmental quality, and develop effective remediation strategies are cover in this course. The course is organized into following blocks:

Block 1 covers the atmospheric chemistry and pollution

Block 2 deals the water chemistry and pollution

Block 3 describes in brief of soil and noise pollution

Block 4 deals the instrumental techniques and pollution control

PGEVS-102N

Rajarshi Tandon Open

University, Prayagraj

Environmental Chemistry

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Block-1

PGBEVS-102N

Environmental Chemistry

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Block- 1

Atmospheric Chemistry and Pollution

UNIT -1
Atmospheric composition and Pollution

UNIT-2
Ozone Chemistry and Photochemical Smog

UNIT-3
Sampling and Air Pollution Abatement

Introduction

This first block of environmental chemistry consists of following three units:

Unit-1: Atmospheric Chemistry and Pollution- this unit deals the Composition of air and air pollutants. The source, sink and concentration air pollutants like carbon monoxide (CO), Nitrogen Oxide (NOx), Sulphur Oxide (SOx), hydrocarbon are discuss in this unit. In addition the particulates matter, acid rain, greenhouse and greenhouse effect, global warming potential of gases and its effects is briefly described.

Unit-2: Ozone Chemistry and Photochemical Smog- deals the atmospheric ozone, formation and depletion of ozone in stratosphere. It also discuss the role of free radicals in ozone depletion, and climate change, however the Montreal protocol and formation of Smog like London/Los Angeles and peroxyacetyl nitrate (PAN) also discussed.

Unit-3: Sampling and Air Pollution Abatement: this unit deals the sampling methods and adsorption and absorption of gaseous pollutants. In addition its also discuss the types of particulate matter, control of particulate matter and collection equipment like settling chamber, cyclones, filters, electrostatic precipitator and scrubber and wet collector.

Unit-1: Atmospheric Composition and Pollution

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1.1.Introduction

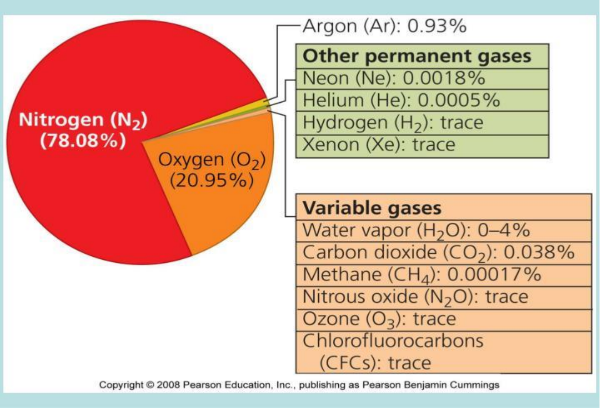
The atmosphere is a layer of gases that surrounds the Earth and plays a critical role in supporting life on our planet. It provides us with oxygen to breathe, protects us from harmful solar radiation, and regulates the Earth's climate and temperature. The composition of the atmosphere is made up of various gases, with the most abundant ones being nitrogen, oxygen, and argon. However, human activities have significantly altered the composition of the atmosphere by releasing pollutants and greenhouse gases. Air pollution refers to the presence of harmful substances in the air that we breathe. These pollutants can come from natural sources, such as wildfires and dust storms, but the majority of air pollution comes from human activities such as burning fossil fuels, transportation, and industrial processes. Some of the common air pollutants include carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter, and ozone. Exposure to these pollutants can have significant health effects on humans and other living organisms, including respiratory and cardiovascular diseases, as well as impacts on the environment, such as acid rain and climate change.

Objectives:

- To discuss the atmospheric composition of air
- To discuss primary and secondary air pollutants and its effects
- To discuss chemistry of air pollutants
- To discuss acid rain, global warming and greenhouse effects

1.2.Composition of air

Air is a mixture of nitrogen, oxygen, carbon dioxide, water vapors, and some other gases commonly referred to as the atmosphere. The composition of air can vary depending on location and altitude, but on average, it is composed of, Nitrogen (N_2): 78.08%, Oxygen (O): 20.95%, Argon (Ar): 0.93%, Carbon dioxide (CO_2): 0.04%, Neon (Ne), Helium (He), Methane (CH_4), Krypton (Kr), Hydrogen (H_2), and Xenon (Xe): together they make up less than 1% of the atmosphere. There are also trace amounts of other gases, including water vapor, ozone, and various pollutants. It's important to note that the composition of air can be affected by human activities, such as burning fossil fuels or industrial processes, leading to an increase in the concentration of greenhouse gases like carbon dioxide and methane.



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The other elements, it forms an oxide bond. Oxygen is quite flammable. The oxygen cycle is responsible for the exceptionally high oxygen gas content on Earth. This biogeochemical cycle (oxygen transfer between biotic and abiotic components) explains how oxygen moves between and among the atmosphere, biosphere, and lithosphere, the planet's three main oxygen reservoirs. Photosynthesis, which created the atmosphere of the modern Earth, is the major driving factor behind the oxygen cycle.

1.3.Air pollutants

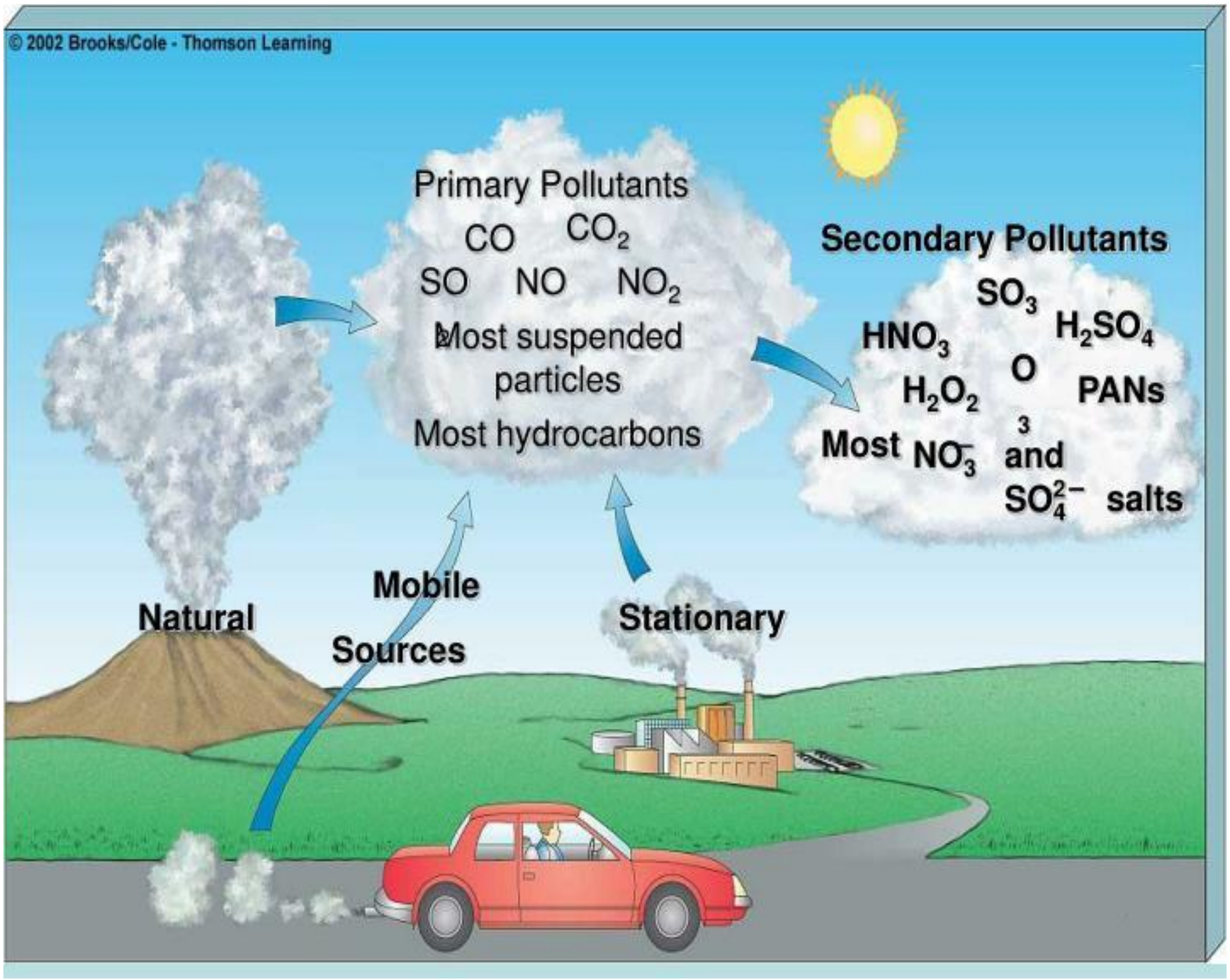
Air pollutants are gaseous in nature at normal temperature and pressure. Several of compound that having boiling points below 200 C is also considered air pollutants. Air pollutants may be inorganic and organic gaseous materials. Inorganic gases pollutants are noxious gases pollutants likeNO_x, SO_x, CO, H_2S), NH_4^+, Cl, HF, NCl, PO_x), NCN, Br, and mercaptonetc. Whereas other gaseous pollutants such as hydrocarbon (C_xH_y) such as CH_4, C_3H_8,C_2H_4,C_6H_6, C_8H_{18} and other pollutants such as formaldehyde, acetone vapors, alcohols, organic acids methyl isocyanides and chlorinated hydrocarbon etc., are considered as organic gaseous pollutants.

1.3.1. Primary air pollutants

We know that all physical and chemical elements that have adversely affect on living beings and in nature are called pollutants. If any substance IS formed or emitted from source is called primary pollutants. Primary pollutants can be originated either by natural sources (sandstorms and volcanic eruptions) or anthropogenic (human influence) activities. For example, the major primary pollutants are Oxides of Sulphur, Oxides of Nitrogen, Oxides of Carbon, Particulate Matter, Methane, Ammonia, Chlorofluorocarbons, Toxic metals etc.

1.3.2. Secondary air pollutants

Primary pollutants are responsible for the production of secondary pollutants when it reacts in the atmosphere or with other pollutants in atmosphere. Thus, the secondary pollutants are those pollutants that not directly emitted from particular source, but formed after releasing particular source in to atmosphere. It is difficult to control secondary pollutants they have different ways of synthesizing. Sometime secondary pollutants originate naturally in environment and cause problem like photochemical song, some other Example of secondary pollutants are ozone and secondary organic aerosol (haze).



1.3.3. Indoor air pollution

When you think about indoor pollution, you thing about emission of smog, power plants, cars and trucks and other unpleasant smell of gases release form different house hold activity. Actually, the indoor pollutant worsening of interior air quality, thus indoor pollution is physical, chemical, and biological properties of air in a home, institution, or commercial facility's indoor environment. Indoor air pollution is a very real and dangerous thing because indoor air is far more concentrated with pollutants than outdoor air. It's estimated that 2.2 million deaths each year are due to indoor air pollution (compared to 500,000 deaths from outdoor air pollution). There are many sources of indoor air pollution, but they are different for developed and developing nations. There are several factors in both rural and urban areas that are responsible for indoor pollution, indoor pollution is ten time more than outer air pollution because in enclosed rooms encourage the accumulation of possible contaminants more than open ones. Indoor pollution is also considering household pollution because it generated inside homes or buildings through occupants' activities, such as cooking, smoking, use of electronic machines, use of consumer products, or emission from building materials. Harmful pollutants inside buildings include carbon monoxide (CO), volatile organic compounds (VOCs), particulate matter (PM), aerosol, biological pollutants, and others. Indoor pollutants have both short term and long-term effects and cause serious threat to human health. Indoor pollutants are complex mixture of various gases components and other pollutants, its concentration depend on sources, emission rate, and ventilation conditions, therefore, it is very important to identify their main sources and concentrations and to devise strategies for the control and enhancement of indoor air quality. The concentration of indoor pollutants can be reduced by using proper measuring its concentration, reducing its source, by using eco-friendly fuel resources, and making ventilated building or working place. Inaddition, we can adopt some other practices for low risk of indoor pollution such as -

i. by proving fresh air or oxygen for human respiration in working place
ii. by diluting indoor air pollutants
iii. by using outdoor air with a low aerosol concentration to control aerosols inside buildings
iv. by controlling internal humidity
v. by adopting proper ventilation system using natural and mechanical system

1.3.4. Outdoor air pollution

Outdoor air pollution is referring to ambient air pollution that considers all environmental pollution except indoor pollution. The common source of outdoor pollution is emissions caused by combustion processes from motor vehicles, solid fuel burning and industry. Apart from that, smoke from bushfires, windblown dust, and biogenic emissions from vegetation (pollen and mold spores) also considered as outdoor pollutants. However, the carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter of different size fractions, and sulfur dioxide) are common in outdoor air and can harm human health and the environment. Outdoor pollution can some form mobile or stationary sources

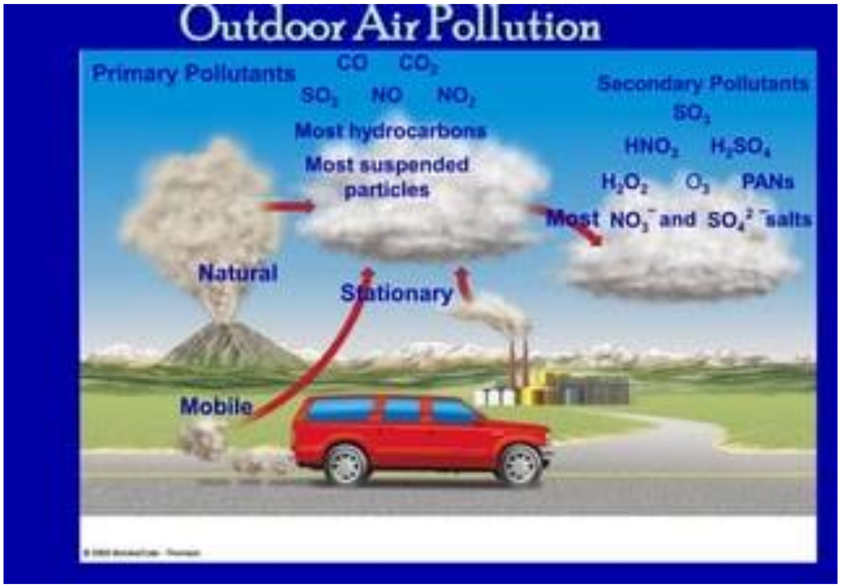
Major source- example Vehicular pollution

Stationary source-example power plants and factory

Is also comes from point and non-point source:

Point sources- specific spot where large quantities of pollutants area like discharge power plants and factory etc.

Non-point source- more diffuse considering of many small source like automobiles



Outdoor pollution is considered as global problem because create measure environmental health problem. WHO estimates that in 2016, some 58% of outdoor air pollution-related premature deaths were due to ischemic heart disease and stroke, while 18% of deaths were due to chronic obstructive pulmonary disease and acute lower respiratory infections respectively, and

6% of deaths were due to lung cancer. We can adopt some other practices for low risk of indoor pollution such as -

- **i.** By adopting eco-friendly fuel and clean technology.
- **ii.** By managing and monitoring of urban and rural waste.
- **iii.** By ensuring access to affordable clean household energy solutions for cooking, heating and lighting.
- **iv.** By adopting clean and environmental friendly transportation system.
- **v.** By using low-emissions fuels and renewable combustion-free power sources
- **vi.** By adopting strategy for waste reuse, recycle and reduce techniques and also biological treatmentmethods.

1.4.Chemistry of air pollutants

We know the air pollution commonly occurs by the chemical elements when it present above their standard concentration. Mostly chemical elements that present in nature do not have adverse effect even present maximum concentration but after chemical reaction, they get converted in to more complex pollutants. Thus, it’s necessary to all to understand the chemistry of air pollutants. The EPA has identified six pollutants as “criteria” air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria (science-based guidelines) for setting permissible levels. These six pollutants are carbon monoxide, lead, nitrogen oxides, ground-level ozone, particle pollution (often referred to as particulate matter), and sulfur oxides. On the basis of human health EPA set the same set of limits for these pollutants known as primary standards, while on the basis of prevent environmental and properties damage set of limits called secondary standards. Chemical nature of pollutants directly and indirectly affects the set of limits. Sometime highly toxic element converts in to non-toxic after chemical reaction. However, the formation of new species may be toxic or non-toxic depends on the nature of climatic factor.

1.4.1. Carbon monoxide (CO):

Carbon Monoxide (CO) is a colorless, odorless gas emitted from combustion processes, specifically, the incomplete combustion of fuel. During combustion process, if there not enough oxygen available to create carbon dioxide as a byproduct than carbon monoxide creates instant. The biggest sources of carbon monoxide come from automobile, especially when they are moving slowly or when the engine is idle. Carbon Monoxide is less common than atmospheric carbon but more dangerous. During incomplete combustion of fossil fuel CO produce as more toxic gases that inhibit respiration in living being by binding irreversibly to hemoglobin in red blood cells and form carboxyhemoglobin that is 210 times faster than O_2, The carboxyhemoglobin starving vital organs such as the brain, nervous system tissues and the heart of oxygen, reducing their ability to work properly. Formation of carboxyhemoglobin decreases the overall O_2 caring capacity of blood to cell resulting into oxygen deficiency hypoxia.

$$2C + O_2 \rightarrow 2CO$$

$$CO_2 \rightarrow 2CO$$

$$CO_2 \xrightarrow{1200℃} CO + O \text{ (Photochemical reaction)}$$

$$CO + OH + O_2 \rightarrow CO_2 + HO_2^{\circ}$$

1.4.2. Nitrogen Oxide (NO_x):

Nitrogen is the major element (78 %) in atmosphere and chief components and essential for animal and plants. This atmospheric nitrogen that releases form biological and anthropogenic activity get converted into oxides of nitrogen. The oxides of nitrogen involved in air pollutants by NO_x, are N_2O, NO, NO_2, N_2O_3, and N_2O_5. N_2O not known to cause of air pollution problem. In atmosphere, due to lighting nitrogen converted into nitrogen oxides. The natural activity that produces nitrogen oxides is lightning. When lightning strikes dioxide and dinitrogen combine at very high temperatures. Nitrogen oxide also produces when fossil fuels are burn at high temperature, but can also be formed naturally by lightning strikes. Nitric acid (NO) is the principal component of oxides of nitrogen. It is formed by the composition of $N_2$and O_2during light discharge and by bacterial oxidation of ammonia in soil.

Nitric acid (NO) on coming in contact with air or oxygen but it really combines to form NO_2. Nitrogen Dioxide (NO_2) is one of the most dangerous pollutants. Nitrogen dioxide (NO_2) which is a reddish, brown gas that has an unpleasant smell and is poisonous in high concentrations. NO_2 is the chief constituent of photochemical smog in the metropolitan cities. It has a red-brown color that one often sees over traffic jams and in fumes coming out of factories. These can form secondary pollutants and can result in environmental problems such as acidification and nitrogen enrichment. The average residents time of NO and NO_2 in the atmosphere area 4 days and 3 days respectively. This indicates that natural process including photochemical reactions, take care of NO_x the product being HNO_3. The HNO_3 is precipitated as nitrate salts in either rainfall or as dust.

$$N_2 + O_2 \xrightarrow{1200-1700℃} 2NO$$

$$2NO + O_2 \rightarrow 2NO_2$$

$$O_3 + NO_2 \rightarrow NO_3 + O_2$$

$$NO_3 + NO_2 \rightarrow N_2O_5$$

$$N_2O_5 + H_2O \rightarrow 2HNO_3$$

Reaction at higher altitude

$$H_2O + h\upsilon \rightarrow N_2 + O$$

$$N_2O + O \rightarrow 2NO$$

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

1.4.3. Sulphur Oxide (SO_x)

Oxides of sulphur that is SO_2, SO_3, H_2S carbon sulphide (COS), carbon disulphide (CS_2) dimethyl sulphide $[(CH_3)_2S]$ and sulphates (NH_4^+) are the most serious air pollutants. Sulphur oxides are colorless gas with a penetrating, choking odour. Sulphur oxides are emitted in atmosphere by both natural and anthropogenic activity. However, the largest source of SO_2, emission is volcanic activity. SO_2, is most common and the second most contributors of air pollutants as it accounts for about 29% of the total weight of all pollutants. SO_2, mainly found in lower atmosphere and colorless gas that can be detected by taste and smell in the range of 1,000 to 3,000 micrograms per cubic meter ($\mu g/m^3$). However, it is soluble in water in water and form acid when react with water in atmosphere. About 30% sulphur dioxide converted into aerosol that can be removed by wet or dry deposition methods. Higher concentration of $SO_2$is found atmosphere that depend on the environmental factor like wind speed, temperature, humidity, and topography, its causes most of health and vegetative damage.

The coal fired power stations are mainly responsible for the SO_2 pollution and burning of fossil fuel, manufacture of sulfuric acid, fertilizers and smelting industry etc. also responsible for SO_2 pollution. Emissions from domestic coal burning and from vehicles can also contribute to high local ambient concentrations of sulfur dioxide. However, sulphur trioxide (SO_3) is an intermediate product during the manufacture of sulphuric acid. Sulfur oxide emissions cause adverse impacts to vegetation, including forests and agricultural crops. In the atmosphere SO_2does dot remain in gaseous state for a long time, very soon it reacts with atmospheric moisture in presence of sunlight form sulphuric acid, which finally comes on the land along with acid water (acid rain).

$$S + O_2 \rightarrow SO_2$$

$$2SO_2 + O_2 \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3 \xrightarrow{\text{Dust}} H_2SO_4 \text{ (Acid)}$$

At high temperature in atmosphere givesSO_2° radicals

$$SO_2 + h\upsilon \rightarrow SO_2^{\circ}$$

Hydrogen radical present in the photochemical smog also contributes to the oxidation of SO_2

When SO_2combined with water molecules its produce acid rain

$$OH + SO_2 \rightarrow HOSO_2$$

1.4.4. Hydrocarbon

Hydrocarbons are organic matter it's considered as pollutants when its quantities increase in air. In India, the main sources of hydrocarbon are automobiles; it produces number of hydrocarbons such as CH_4, C_2H_2, Benzene, Propane, Toluene, Benzopyrene and PHAs (Polycyclic aromatic hydrocarbons). Generally, hydrocarbon occurs in atmosphere produce by natural and anthropogenic sources.

1.4.4.1.Natural sources of hydrocarbon:

a) **From Microbial Degradation:** Methane (CH_4) is the major naturally occurring hydrocarbon emitted in atmosphere. It is produced by bacterial degradation (decomposition) of organic matter in soil, water and sediments.

$$2CH_2O \xrightarrow{\text{bacteria}} CH_4 + CO_2$$

b) From Ocean: Hydrocarbon release maximum are of water surface of ocean by plants and animal's activities

c) From Rhuminants: Human activities contributes nearly 20% of the hydrocarbons emitted to the atmosphere every year and animals contributes about 80-85 million tons of methane in the atmosphere every year by animals

d) **From Forest Fire**: burning of green tree and fossil fuel emitted hydrocarbons.

1.4.4.2.Anthropogenic sources:

a) Transportation: A more important source of hydrocarbon is an automobile exhaust, which contains significant amount of unburned hydrocarbon is complete combustion does not take place.

b) Figurative emission from Industries: Industrial process like processing, storage, transfer of products etc. contribute the next largest source of hydrocarbons. The evaporation of organic solvents likeC_6H_6, $C_6H_5CH_3$, CCl_4, $CHCl_3$, etc. emit about 10% hydrocarbon in air during industrial operation. These solvents are ingredients of paints, varnishes, lacquers, undercoating and other products. During their manufacture, large quantities of reactive hydrocarbons are emitted into atmosphere.

c) Figurative emission form house hold: Some hydrocarbons are emitted from daily occurring process by human activities such as burring waste inorganic agricultural martial and from some other burning martial etc. Reactions of hydrocarbons in atmosphere in the presence of nitrogen oxides (NO_2,) and responsible for photochemical smog (Las Angeles). Approximate natural emission of hydrocarbons is about 520 x 10^6 tones/year at in 1998 of which petroleum products 55%, coal about 3.3% woods 2.3%, emission and refuse burning about 20.2% and solvents evaporation about 11.3%.

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

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

$$O_3 + C_xH_y \rightarrow RCH_3 + RCHO$$

$$RCH_3 + {}^{\circ}OH \rightarrow {}^{\circ}RCH_2 + H_2O$$

$$^{\circ}RCH_2 + O_2 + M \rightarrow RCH_2OO^{\circ} + M$$

$$RCH_2OO^{\circ} + NO \rightarrow RCH_2O^{\circ} + NO_2$$

$$RCH_2O^{\circ} + O_2 \rightarrow RCHO + HOO^{\circ}$$

$$HOO^{\circ} + NO \rightarrow NO_2 + {}^{\circ}OH$$

$$RCHO + {}^{\circ}OH \rightarrow R^{\circ}CO + H_2O$$

$$R^{\circ}CO + M + O_2 \rightarrow RCOOO^{\circ} + M$$

$$RCOOO^{\circ} + NO_2 \rightarrow RCOOONO_2$$

Peroxyacetyl nitrate (PAN)

Photochemical reaction also involves the formation of free radicals form aldehydes

$$CH_3CHO + h\upsilon \rightarrow {}^{\circ}CH_3 + HCHO^{\circ}$$

Ketones, hydrogen peroxide, organic peroxides etc. also yield free radicals which interact with hydrocarbons in atmosphere.

1.4.5. Particulates matter

Particle of small size which is born by air constituents is called particulate matter. The particulate matters are discreet mass of any material that exists as liquid or solid in the atmosphere and of microscopic dimensions. They are found 0.001 um to several hundred um in dimension with large surface area hence present good side for absorption of various inorganic and organic gaseous which increases heterogeneous phase reaction in the atmosphere including scattering of life. The particulates matters are influence the climate through the formation of clouds and smokes they also absorbs solar radiation and reduce visibilities. About two thousand million tones of particulate matter per year releases form natural resources. About 450 million tons of particulates matte in year is emitted form man made sources as burning of fossil fuel. Industrial operation etc. types of particulate matter on the basis of size they are dividing into following types:

Smoke: smoke particulates consist solid and liquid particles ranging from 0.05 to 1.0 micron which emitted mostly from vehicles.

Dust: Dust is composed of fine solid particles and their size range from 1 micron to 100 micron (μ). Dust particles are formed by sand from sand blasting saw dust form wood works and coal etc.

Mist: Mists are liquid particles are formed by condensation of a vapor having a size less than 10 micron. For example

$$\mathrm{SO_2(gas)} \xrightarrow{22^\circ\mathrm{C}} \mathrm{SO_3\ (liquid)}$$

Spray: It constitutes quid particles obtained from the present liquid process of mechanical disintegration like atomization.

Fumes: fumes are generally obtained by condensation of various by sublimation, distillation, calcinations and by several other chemical reactions.

Source of particulate matter:

The particulate matters are release from natural and anthropogenic sources

a) **Natural sources:** particulate matter release form different natural resources in which some are as volcanic actions, forest fire, wind, soil erosion etc. are sources of particulate matter.
b) **Anthropogenic sources:** combustion of fossil fuels, industrial operations, transportation, industrial fugitive process etc. is the sources of emission of particulate matter by manmade process.

Formation of particulate matter:

The formation of particulate matter is two types i.e., inorganic and organic particulate matter.

Inorganic particulate matter:

This is also two types such as physical and chemical. Physical methods involving in formation of particulate matter

- Dispersion process: mainly yield dispersion process example dusts.
- Adhesion of small particles by chemical process by yields particles of the size rangingfrom 10-20 μ.

- Natural resources also produce dispersed aerosols from sea sprays, windblown and dust during cultivation and volcanic dust etc.
- By coagulation, aggregation, separation, absorption also results in formation of particulates matter.
- Chemical methods involved in formation of particulate matter: they are generally originated from metallic oxides, sulphides and carbonates etc.
- These are produced when fuels containing metals are burned for example

a) The formation of Fe_3O_4 is formed during the combustion of pyrites containing coal.

$$3FeS_2 + 8O_2 \rightarrow Fe_3O_4(\text{particulate matter}) + 6SO_2$$

b) Calcium carbonate in ashes formation of coal gets converted to calcium oxide which emits into the atmosphere through stack.

$$CaCO_3 \xrightarrow{\Delta} CaO_{\text{particulatr matter}} + CO_2$$

c) Lead halides are generated by the combustion of leaded gasoline

$$Pb(C_2H_5)_4 + O_2 + C_2H_4Cl_2 + C_2H_4CBr_2 \rightarrow CO_2 + H_2O + PbCl_2 + PbBr_2 + PbBrCl$$

d) Aerosol mist are formed by the oxidation to H_2SO_4

$$2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_{4\text{(From decomposition)}}$$

Aerosols of natural origin with diameter less than 0.2 μ are called Aitken particles these are normally bacteria, fogs, pollen grains volcanic ash etc.

Organic particulates matter:

- It originates from wind variety auto mobiles and vegetation. Polycyclic aromatic hydrocarbon (PAHs) like chrysene benzo fluoranthene, benzopyreneetc. are some organic particulate matters of is carcinogenic matter. It mainly occurs in urban atmosphere is about 20 ug/m^3 in upper atmosphere.
- PAHs originate from paralysis of higher parameter present in fuels and plant materials high molecular weights are paralyzed to produce $C_{10}H_{22}$. While under goes further formation of PAN compounds.
- Main PAH compounds are absorbed in soot particles (size 1-10 μ) usually these are graphite crystal, large surface area to absorbs to resulting growth of particulates under gravity they effect the structure of vegetation.

1.5.Acid rain

Acid rain is the phenomenon, where precipitation of acid occurs in the form of rain as simplest manner commonly known as acid rain. The term of acid rain fist coined by Robert Angus Smith in 1872. It is naturally slightly acidic due to dissolved carbon dioxide. The term acid refers to an excess of H^+ ions in water solution. Hydrogen ions are normally balanced by anions, $2SO_4^{2-}$, NO_3^- and to some extent by $Cl^-$and organic anions, e.g., acetate(CH_3COO^-) and formate $(HCOO^-)$ ions.

Acid rain occurs in different form such as snow, sleet, fog, dew etc. which is unusually acidic i.e., containing a higher concentration of hydrogen ions than normal rain. The acid rain has adverse effect on environment and human being. Due burning of fossil fuels and vehicular emission of sulphur dioxide and nitrogen oxides are responsible of acid rain or acid precipitation. Some other natural phenomenon such as volcanoes, oceans, and biological decay and forest fires also enhance the acid rain precipitation. The effects of acid rain on trees and freshwater bodies were first observed in Scandinavian countries during the 1970s and 1980s. Acid rain and acid precipitation depend upon the chemical nature of air pollutants and moisture in the atmosphere. Winds can blow $SO_2$and NO_xover long distances and across borders making acid rain a problem for everyone and not just those who live close to these sources. Thus, acid rain day by day becomes a global problem. Air pollution plays a huge role in acid rain as air is the medium in which pollutants released combine with rain water or atmospheric moisture and are washed down to the surface of the earth.

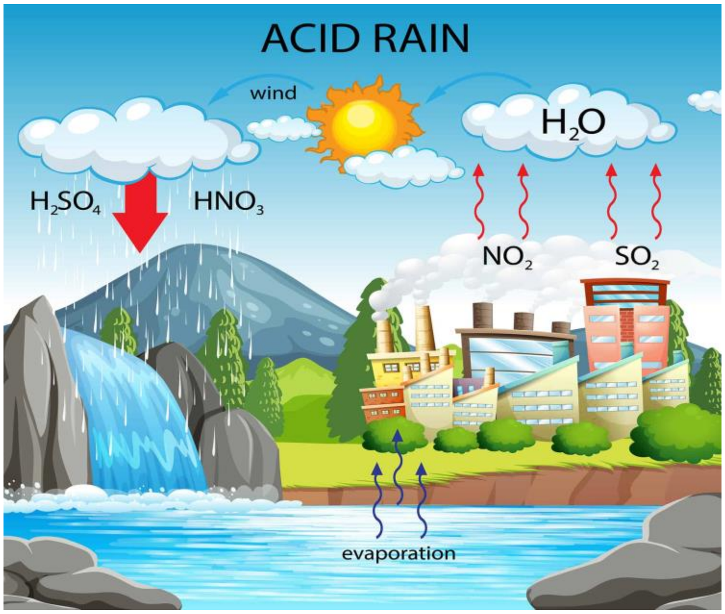
The acidic deposit occurs in two way as dry deposition and wet deposition, wet deposition is any form of precipitation which removes acids from the atmosphere and places them on the surface of the earth. In the absence of precipitation, dry deposition of polluting particles and gases sticks to the ground through dust and smoke.

a) Wet deposition: In wet areas, acid falls with rain, sleet, hail, snow and fog.

b) Dry deposition –This refers to acidic gases and particles which get deposited on soil, vegetation and water on earth’s surface

1.5.1. Acid rain formation

Acid rain is formation is chemical phenomenon, it occurs when the atmospheric gases that release from different resources are reacted water forms acid rain. For example, when nitrogen oxide with oxygen to form nitrogen dioxide and nitrogen dioxide dissolves in water to form nitric acid which is washed down as acid rain.



$$2NO(g) + O_2(g) \rightarrow 2NO_2$$

$$2NO_2(g) + H_2O\ (l) \rightarrow HNO_2 + HNO_3$$

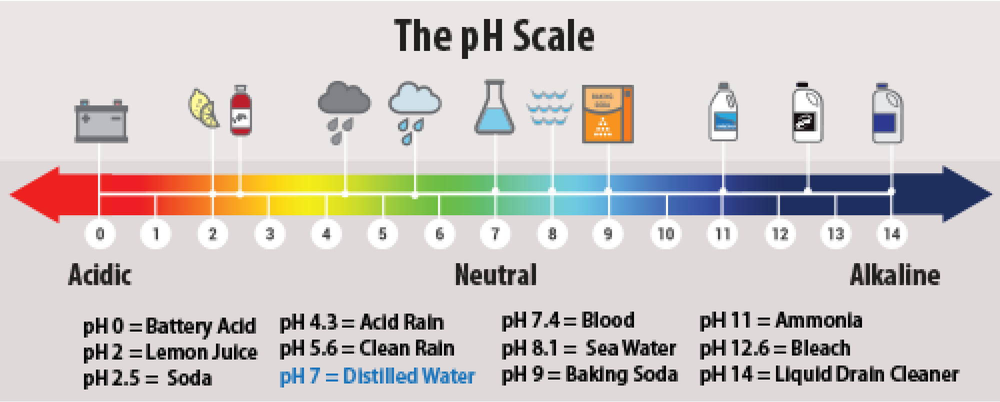
However, the major form of acid rain occurs when sulphur dioxide reacted with oxygen to form sulphur trioxide, which further dissolves in water to produce sulphuric acid.

$$SO_2(g) + \frac{1}{2}O_2(g) \rightarrow SO_3(g)$$

$$SO_3(g) + H_2O\ (l) \rightarrow H_2SO_4\ (aq)$$

1.5.2. Measuring Acid Rain

Water is acidic or basic in nature can be measured by pH meter. Thus, the acidic and alkalinity of rain water is measured using a pH scale for which 7.0 is neutral and less than 7 is acidic and greater than 7 is alkaline is nature. Normal rain has a pH of about 5.6; it is slightly acidic because carbon dioxide (CO_2) dissolves into it forming weak carbonic acid. Acid rain usually has a pH between 4.2 and 4.4. When acid deposition is washed into lakes and streams, it can cause some to turn acidic.



References: What is Acid Rain? | US EPA

City	**pH**	**Year**
Jaipur	6.7 – 8.45	1996 - 2006
Delhi	6.7	1996
Agra	7.0	1991
Pune	6.5	1996
Kalyan	5.7	1989
Chembur	6.44	1994
Goa	6.3	1996

Source of table: Rainwater pH value at selected Indian locations (Misra et al., 2013)

1.5.3. Effects of acid rain

Acid rain adversely impacts freshwaters, forests, soils, killing aquatic life-forms, and insects. In addition, this occurrence causes damage to buildings and impacts human health adversely.

Surface waters and aquatic animals:

In aquatic environment the increasing concentration of H^+ion due to addition of acid rain water decreases the pH value of water that may arias harmful effects on animal and fisher by change life cycle and reproduction process. However, it is found that, fish eggs may not hatch at pHs lower than 5 and further lower pHs can destroy adult fish. Apart from fisher's other aquatic animal are affected when natural habitat like for lakes and rivers is getting acid water from different sources. Thus, we can say acid rain is reducing aquatic biodiversity by destroyed some fish species and insect lives.

Soils:

In soil, there is lots of chemical already exited, but when acid rain enters in soil profile it changes the physical and chemical nature of soil. Due to change of physiochemical properties of soil a lot of microbes that are essential for cultivation get destroyed due to change in low pH of soil. The enzymes embodied in these microbes are changed in shape by the acid and are no longer able to function i.e., denatured. Acid rain leached out plant nutrients from soil, particularly the base cations, such as magnesium, calcium and potassium are leached out. These are replaced by hydrogen ions owing to ion exchange. The increased acidity combined with nutrient deficiency leads to decrease in soil fertility. The vital nutrient phosphorus is available in soil as phosphate. The aluminum ions, Al^{3+}, are able to bind the phosphate very strongly and so the latter becomes unavailable to plants. An increase in acidification of soil, results in the leaching of potentially toxic metal ions such as aluminum, cadmium, manganese, copper, iron, etc.

Forests and other vegetation:

The forests at high altitude are more susceptible to damage due to their exposure to the base of low-level clouds, where the acidity may be high. Acid rain can also damage other plants, however its impact on food crops is reduced by the use of fertilizers and lime to swap lost nutrients. Al^{3+}, ions damage the root fibers and lead to forest decline. Acidity coupled with presence of tropospheric ozone and other oxidants cause stress, which when combined with drought, temperature extremes and disease and insect attack, leads to forest decline.

Health effects on humans:

Human health is not directly affected by acid rain since the acids present in the rainwater are in dilute form. Nevertheless, the particulates like nitrogen oxides and sulfur dioxide that contributes to acid rain adversely impacts the humans. Increased levels of these fine particulates in the air create lung and heart troubles including bronchitis and asthma.

Effects of acid rain on building material:

Acid rain and acid deposition causes buildings and monuments to deteriorate. Many buildings and statues of historical importance are built with stone such as marble, containing calcium carbonate. Sulphuric acid in acid rain converts calcium carbonate into calcium sulphate, which can cause discoloration and pitting of the stone. The yellowing of the Taj Mahal, earlier famous for its pure white marble structure, is an example of this phenomenon. The amount of acid in rainwater decides its effect of weathering of rocks. When natural rain water(pH = 5.6) falls on limestone derived rocks, as in Rajasthan, etc., the reaction with limestone neutralizes the acid and limestone dissolves

Prevention of acid rain

- Prevention of acid rain can be carried out by curtailing the use of fossil fuels by simple steps like more walking and cycling instead of driving.
- Switching use of low sulphur coal, desulphurisation of coal before burning, removing sulphur oxides from waste gases coming out of chimney stacks, road traffic restriction, bringing more renewable energy sources.
- Being responsible citizens, one should be aware of the harmful effects they cause and of the industries which give out nitrogen and sulphur compound wastes unethically.

1.6.Greenhouse

Greenhouse means an inflated structure covered with a transparent material that make warm environment inside even during winter. In another world, Greenhouse is building designed for protection of seasonal plant against excessive cold and heat, means mentioned desired environmental condition of cultivated plant. The greenhouse may be made up of glass, ordinary bricks or timber materials with a normal proportion of window space and some means of heating. Greenhouse also called glasshouse because it is cheap and sophisticated forms of heating became available, greenhouse is very useful technology for cultivation of off-season production of high value vegetables and food crops in cold climate. Mid-19th century the greenhouse had developed to control of hostile environment for protection of some particulate plant, but end of 19th century is becomes useful for exotic plants species and adopted vast in greenhouse culture in England and some other country. However, now modern greenhouse technology is widely accepted that is usually a glass- or plastic-enclosed framed structure used for the production of fruits, vegetables, flowers, and any other plants that require special conditions of temperature. The basic structural forms are the span-type greenhouse, which has a double-sloped, or A-shaped, roof, and the lean-to greenhouse, which has only one roof slope and leans against the side of a building. Greenhouse is getting warmness from greenhouse gases.

The greenhouse gases are trap the heat from atmosphere is called greenhouse gases. In the atmosphere the primary greenhouse gases are watervapor (H_2O), carbondioxide (CO_2), methane (CH_4), nitrousoxide (N_2O),and ozone (O_3). These greenhouse gases absorb and emit radiant energy within the thermal infrared range, causing the greenhouse effect, thus the heat of increase greenhouse increases. The solar radiation reaches on the earth surface, the earth surface absorbs and emits this solar ration. The earth surface emitted or returns back the solar ration with high wavelength (Infrared radiation). This high wavelength means infrared radiation absorbed by greenhouse gases that lead to the heating of the surface of the planet. However, the greenhouse effects areenhanced due to increase the concentration of greenhouse gases, thus it need to understand and distinguish natural greenhouse effect and enhanced greenhouse effect. The natural greenhouse effect is caused by the natural amounts of greenhouse gases, and is vital to life. In the absence of the natural greenhouse effect the surface of the Earth would be approximately 33°C cooler. Natural greenhouse effects occur due to present of ambient concentration of greenhouse gases, while the enhance greenhouse effects is produce due to addition of greenhouse gases.

1.7.Global warming

Global warming refers to the long-term increase in the Earth's average surface temperature due to the buildup of greenhouse gases in the atmosphere. Greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, trap heat from the sun's radiation and prevent it from escaping back into space, causing the Earth's temperature to rise. The main cause of global warming is human activities, such as burning fossil fuels, deforestation, and agriculture, which release large amounts of greenhouse gases into the atmosphere. The effects of global warming can be seen through rising sea levels, melting glaciers, more frequent and severe weather events, and shifts in ecosystems, among other things. To mitigate the impacts of global warming, governments, organizations, and individuals have taken various actions to reduce greenhouse gas emissions and promote sustainable practices. These include using renewable energy sources, reducing energy consumption through energy-efficient buildings and appliances, and transitioning to low-carbon transportation. Addressing global warming is crucial to safeguard the planet's future and the well-being of all living beings on it. The Paris Agreement, signed in 2015 by nearly every country in the world, aims to limit global warming to well below 2 ℃above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 ℃. Achieving these goals will require collective efforts and sustained action from all sectors of society.

1.7.1. Causes and effect and mitigation

The main cause of global warming is the increase in the concentration of greenhouse gases, primarily carbon dioxide, in the atmosphere. The main sources of these gases are human activities, such as burning fossil fuels (coal, oil, and gas) for energy, deforestation, and land use changes. These activities have significantly increased the levels of carbon dioxide in the atmosphere from about 280 parts per million (ppm) before the industrial revolution to over 400 ppm today.The increased concentration of greenhouse gases in the atmosphere traps more heat from the sun's radiation, causing the Earth's temperature to rise. The effects of global warming can be seen across the planet, including:

- **Rising temperatures:** The average global temperature has increased by about 1 ℃ (1.8 ℉) since the late 1800s.
- **Melting ice:** Ice in the Arctic, Antarctic, and glaciers around the world is melting at an alarming rate, leading to rising sea levels.
- **More frequent and severe weather events:** Global warming is causing more intense and frequent heat waves, droughts, wildfires, hurricanes, and floods.
- **Shifts in ecosystems**: Many plant and animal species are being affected by global warming, with some species moving to new locations, changing their seasonal behaviors, or even becoming extinct.
- **Ocean acidification:** The oceans absorb about 25% of the carbon dioxide emissions from human activities, causing the acidity of seawater to increase, which can harm marine life.

The effects of global warming have significant implications for human health, economies, and the environment. Addressing global warming will require collective efforts to reduce greenhouse gas emissions and promote sustainable practices, including using renewable energy sources, improving energy efficiency, and shifting towards more sustainable land use practices.

Mitigating global warming will require collective efforts from governments, businesses, and individuals around the world. The Paris Agreement, signed in 2015, aims to limit global warming to well below 2°Cabove pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 °C. Achieving these goals will require sustained and ambitious action from all sectors of society. The mitigation of global warming involves actions to reduce greenhouse gas emissions and limit the amount of heat-trapping gases in the atmosphere. Some of the key strategies for mitigation include:

- The use of renewable energy sources such as solar, wind, and hydropower can significantly reduce greenhouse gas emissions from the electricity sector.
- Improving the energy efficiency of buildings, appliances, and transportation can reduce energy consumption and greenhouse gas emissions.
- Deforestation is a significant source of greenhouse gas emissions, and efforts to reduce deforestation and promote reforestation can help absorb carbon from the atmosphere.
- The transportation sector is a major source of greenhouse gas emissions, and shifting to low-carbon transportation options such as electric vehicles, public transportation, biking, and walking can help reduce emissions.
- Technologies that capture carbon dioxide emissions from power plants and industrial processes and store them underground can help reduce emissions.
- Sustainable agricultural practices, such as reducing meat consumption and promoting regenerative agriculture, can help reduce greenhouse gas emissions from the agriculture sector.

1.7.2. Global warming potential

The global warming potential (GWP) of a gas refers to its ability to trap heat in the atmosphere over a given time period compared to carbon dioxide. Global warming potential (GWP) is a measure of how much a greenhouse gas contributes to global warming over a specific time period, usually 100 years, compared to carbon dioxide (CO_2), which is assigned a GWP of 1. It helps assess the relative impact of different gases on climate change. For example, methane has a much higher GWP than CO_2 over a short period, but it dissipates more quickly in the atmosphere. Understanding GWP is essential for climate policy and mitigation strategies. Some common greenhouse gases and their GWPs over a 100-year time horizon are:

Methane (CH_4): GWP of 28-36

Nitrous oxide (N_2O): GWP of 265-298

Hydrofluorocarbons (HFCs): GWPs range from 12 to 14,800 depending on the specific HFC.

Sulfur hexafluoride (SF_6): GWP of 23,500

These gases are often referred to as "climate forcers" because they have a significant impact on the Earth's climate and contribute to global warming.

Understanding the Impact of Greenhouse Gases

Global Warming Potential (GWP) is a crucial concept in climate science and environmental policy. It quantifies the relative contribution of different greenhouse gases to global warming. This metric helps us assess and prioritize efforts to mitigate climate change by understanding how various gases trap heat in the Earth's atmosphere compared to carbon dioxide (CO2), which is the reference gas with a GWP of 1.

GWP measures the heat-trapping capacity of a gas over a specific time horizon, most commonly 100 years. This time frame is chosen to provide a standardized basis for comparing the impact of different gases. GWP values are typically calculated by considering factors such as the gas's radiative efficiency, its atmospheric lifetime, and its absorption of infrared radiation. Greenhouse gases, such as CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, have varying GWP values. Understanding these values is essential for climate scientists, policymakers, and anyone concerned about climate change.

1. Carbon Dioxide (CO_2):

As the baseline with a GWP of 1, CO_2 is used to compare the warming potential of other gases. It is released into the atmosphere primarily from burning fossil fuels, deforestation, and various industrial processes.

2. Methane (CH4):

Methane is a potent greenhouse gas with a GWP of around 25-34 over a 100-year period. However, it has a much higher heat-trapping capacity over shorter time horizons. Methane is released from sources like agriculture, natural gas production, and wetlands.

3. Nitrous Oxide (N_2O):

N_2O has a GWP of approximately 298 over a 100-year period. It is emitted from agricultural and industrial activities, as well as from natural sources.

4. Fluorinated Gases:

Fluorinated gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). These gases have extremely high GWP values, ranging from hundreds to thousands, making them significant contributors to global warming. They are used in various industrial applications like refrigeration, air conditioning, and electronics.

The choice of time horizon for calculating GWP is essential. Shorter time horizons, such as 20 years, emphasize the immediate impact of certain gases like methane, which has a much higher GWP over this period. Longer time horizons, such as 500 years, provide a more extended view of a gas's contribution to warming.

It's important to note that GWP values are not fixed and can be updated to reflect the latest scientific understanding of the gases' warming potential. Additionally, GWP calculations may be region-specific to account for variations in atmospheric conditions and other factors.

The significance of GWP extends beyond scientific curiosity. It plays a pivotal role in shaping climate policy and guiding mitigation strategies. Policymakers and environmental organizations use GWP to prioritize efforts aimed at reducing greenhouse gas emissions.

For example, efforts to reduce methane emissions from agriculture and natural gas production are critical because of methane's high GWP. Similarly, phasing out high-GWP fluorinated gases has become a priority in international climate agreements, such as the Kigali Amendment to the Montreal Protocol. Understanding GWP helps nations set emission reduction targets and evaluate the effectiveness of their climate policies. The Paris Agreement, which aims to limit global warming well below 2°C above pre-industrial levels, relies on GWP values to assess progress toward this goal.

In summary, Global Warming Potential (GWP) is a fundamental tool for assessing the climate impact of different greenhouse gases. It provides a standardized measure of their heat-trapping capacity relative to carbon dioxide. GWP values are vital for shaping climate policy, guiding mitigation efforts, and achieving international climate goals. As our understanding of these gases and their impact on the climate evolves, GWP values may be subject to revision, emphasizing the dynamic nature of climate science and policy.

1.8.Summary

The atmosphere is a layer of gases that surrounds the Earth and provides essential support for life. The composition of the atmosphere is made up of various gases, including nitrogen, oxygen, and argon. However, human activities have significantly altered the composition of the atmosphere by releasing pollutants and greenhouse gases, leading to air pollution. Air pollution refers to the presence of harmful substances in the air that we breathe, which can cause significant health effects and environmental impacts. Some of the common air pollutants include carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter, and ozone. Governments and organizations have implemented various regulations and initiatives to reduce emissions and improve air quality monitoring to address the issue of air pollution.

1.9.Terminal Question

Q.1. What is the atmospheric composition of air? Discuss the role of atmospheric gases.

Answer:--

Q.2. Define the pollution and pollutants? Write the primary and secondary pollutants.

Answer:--

Q.3. Discuss the chemistry of air pollutants.

Answer:--

Q.4. Discuss the role of hydrocarbon for formation of secondary pollutants.

Answer:--

Q.5. What are greenhouse gases? Discuss the greenhouse effects.

Answer:--

Q.6. What is global warming? Discuss the global warming potential and its effects.

Answer:---

1.10. Further suggested Readings

1. Environmental Science, Subhas Chandra Santra, 2011, New Central Book Agency, 3rd Edition.

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3. Atmosphere, Weather and Climate, Barry, R. G. 2003, Routledge Press, UK.

4. Ecology: Theories and Applications, 4th Edition, Peter Stiling, 2001, Prentice Hall.

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Unit-2: Ozone Chemistry and Photochemical Smog

Contents

2.1. Introduction

Ozone is a molecule composed of three oxygen atoms. It is primarily found in the stratosphere, a layer of the atmosphere located between approximately 10 to 50 kilometers above the Earth's surface. The stratospheric ozone layer is often referred to as the "good" ozone because it acts as a shield, absorbing and filtering a significant portion of the Sun's harmful ultraviolet (UV) radiation. The formation of ozone in the stratosphere involves a series of chemical reactions. Ozone undergoes various chemical reactions in the atmosphere. These reactions can occur in the stratosphere, where ozone plays a beneficial role, and in the troposphere, the lower part of the atmosphere where weather occurs. Understanding ozone chemistry is crucial for assessing air quality, studying atmospheric processes, and addressing environmental issues such as ozone depletion and air pollution. Ozone chemistry research helps scientists and policymakers develop strategies to protect the ozone layer, reduce pollution, and mitigate the impacts of ozone on human health and ecosystems.

Objectives

- To discuss the ozone formation and depletion in atmosphere
- To discuss the Ozone in arctic region and its impact on climate
- To discuss the role of free radicals in propagation and depletion
- To discuss the ozone and climate change

2.2. Atmospheric ozone

Atmospheric ozone refers to the presence of ozone gas (O_3) in the Earth's atmosphere. Ozone is a molecule composed of three oxygen atoms bonded together. It is primarily found in the stratosphere, a layer of the atmosphere located approximately 10 to 50 kilometers (6 to 30 miles) above the Earth's surface. The stratospheric ozone layer plays a crucial role in protecting life on Earth by absorbing and blocking a significant portion of the Sun's ultraviolet (UV) radiation. This absorption prevents most of the harmful UV-B and UV-C radiation from reaching the Earth's surface, where it can cause various health issues, including skin cancer, cataracts, and immune system suppression in humans, as well as damage to plant life and marine ecosystems. The formation and destruction of ozone in the atmosphere occur through complex chemical reactions. Ozone is continuously created in the stratosphere when oxygen molecules (O_2) are split apart by UV-C radiation, releasing highly reactive oxygen atoms. These atoms can then combine with other oxygen molecules to form ozone. However, there are also natural and human-made factors that can lead to the depletion of ozone in the stratosphere. The most well-known is the release of certain chemical compounds called ozone-depleting substances (ODS) into the atmosphere. Chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform are examples of ODS that were commonly used in the past in refrigeration, air conditioning, aerosol propellants, and industrial processes. When these ODS reach the stratosphere, they undergo chemical reactions that release chlorine and bromine atoms. These atoms catalytically destroy ozone molecules, breaking them apart and reducing the overall concentration of ozone in the stratosphere. This phenomenon is often referred to as ozone depletion. The most significant depletion of stratospheric ozone occurs in the polar regions, resulting in the formation of the so-called ozone holes. These holes represent areas with extremely low ozone concentrations during specific times of the year, particularly in the spring in the Southern Hemisphere and in the fall in the Northern Hemisphere. To address the issue of ozone depletion, the international community adopted the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987. This treaty aims to phase out the production and use of ODS. Thanks to the protocol's implementation and subsequent amendments, the ozone layer is showing signs of recovery, and the concentrations of most ODS in the atmosphere are declining. Overall, the study of atmospheric ozone is crucial for understanding the Earth's climate, the health of ecosystems, and the potential impacts of human activities on the environment.

2.3. Ozone in stratosphere

The primary chemical reaction involved in the formation and destruction of ozone in the stratosphere is as follows:

Ozone Formation:

Step 1: Photodissociation of Oxygen Molecules

$$\mathrm{O_2 + UV - C\ radiation\ \rightarrow 2O}$$

Ultraviolet (UV-C) radiation breaks apart oxygen molecules (O_2) into individual oxygen atoms (O).

Step 2: Formation of Ozone

$$\mathrm{O + O_2 \rightarrow O_3}$$

The oxygen atoms (O) produced in the previous step reacts with other oxygen molecules (O_2) to form ozone (O_3).

In this reaction, oxygen molecules (O_2) are split apart by UV-C radiation (high-energy ultraviolet radiation). The resulting oxygen atoms (O) are highly reactive and can combine with other oxygen molecules to form ozone (O_3).

Ozone Depletion:

Step 1: Initiation

$$Cl^{\circ} + O_3 \rightarrow ClO^{\circ} + O_2$$

Chlorine radical (Cl°) reacts with ozone (O_3) to form chlorine monoxide radical (ClO°) and oxygen molecule (O_2).

Step 2: Propagation

$$Cl^{\circ} + O \rightarrow Cl^{\circ} + O_2$$

$$Cl^{\circ} + O_3 \rightarrow ClO^{\circ} + O_2$$

The chlorine monoxide radical (ClO°) reacts with atomic oxygen (O) to regenerate the chlorine radical (Cl°) and produce oxygen molecules (O_2). The chlorine radical can then continue the cycle by reacting with more ozone to form ClO°again.

Step 3: Chain Reaction Continuation

$$O + O_3 \rightarrow O_2$$

Atomic oxygen (O) reacts with ozone (O_3) to produce oxygen molecules (O_2), further depleting ozone.

These reactions involving chlorine atoms are typical for ozone depletion caused by chlorofluorocarbons (CFCs) and other ozone-depleting substances (ODS). Similar reactions can occur with bromine atoms from brominated ODS, such as halons.

Chlorine Monoxide Radical Reaction with Ozone:

$$ClO^{\circ} + O_3 \rightarrow Cl^{\circ} + 2O_2$$

The chlorine monoxide radical (ClO°) can react with another ozone molecule (O_3), resulting in the regeneration of the chlorine radical (Cl°) and the production of two oxygen molecules (O_2). This reaction further contributes to ozone depletion.

Bromine Radical Reaction with Ozone:

$$Br^{\circ} + O_3 \rightarrow BrO^{\circ} + O_2$$

Similarly, bromine radicals (Br°) can also react with ozone molecules (O_3), leading to the formation of bromine monoxide radicals (BrO°) and oxygen molecules (O_2). The bromine monoxide radicals can further participate in catalytic cycles, contributing to ozone depletion.

Examples of Ozone-Depleting Reactions:

Reaction with Chlorofluorocarbons (CFCs):

$$\mathrm{CFCl_3 + UVradiation \rightarrow Cl^{\circ} + CFCl_2}$$

Chlorofluorocarbons, such as $CFCl_3$(also known as CFC-11), can be dissociated by ultraviolet (UV) radiation, releasing chlorine radicals (Cl°). These chlorine radicals then participate in reactions that deplete ozone, as mentioned earlier.

Reaction with Halons:

$$\mathrm{CBrF_3 + UVradiation \rightarrow Br^{\circ} + CF_3}$$

Halons, like $CBrF_3$ (also known as Halon-1301), can also undergo dissociation when exposed to UV radiation, producing bromine radicals (Br°) that contribute to ozone depletion.

It's important to note that these reactions are simplified representations of the complex chemistry involved in ozone depletion. It's important to note that these reactions occur in a catalytic cycle, meaning that a single chlorine or bromine atom can destroy multiple ozone molecules before being regenerated and continuing the process. This catalytic destruction is one of the reasons why ozone depletion can have a significant impact on the ozone layer. These reactions play a crucial role in maintaining the delicate balance of ozone concentrations in the stratosphere, influencing the Earth's radiation balance and protecting life on our planet from harmful ultraviolet radiation. The actual chemistry is influenced by various factors, including temperature, pressure, atmospheric conditions, and the concentrations of ozone-depleting substances.

2.4.Ozone in arctic region

In the Arctic region, the presence and behavior of ozone in the atmosphere can vary depending on the season and prevailing atmospheric conditions. Here are some key aspects regarding ozone in the Arctic:

Ozone Concentrations: Ozone concentrations in the Arctic region generally exhibit seasonal variations. The lowest concentrations are typically observed during winter and early spring, while higher concentrations are present in summer and autumn. This is in contrast to the Antarctic region, where a distinct ozone hole forms during the Southern Hemisphere spring.

Polar Vortex: In the winter months, a polar vortex forms over the Arctic, which is a large-scale cyclonic circulation in the stratosphere. This vortex isolates the Arctic air mass, leading to extremely cold temperatures and stable atmospheric conditions. As a result, ozone-depleting reactions can occur within the vortex, leading to localized ozone depletion.

Polar Stratospheric Clouds (PSCs): The presence of polar stratospheric clouds in the Arctic plays a role in facilitating ozone depletion. These clouds provide surfaces for chemical reactions to occur, particularly reactions involving chlorine and bromine compounds. The cold temperatures within the polar vortex enable the formation of PSCs, which can enhance ozone destruction during polar spring.

Ozone Depletion Events: Ozone depletion events in the Arctic can occur primarily during the polar spring (late winter to early spring). During this period, sunlight returns to the polar region, initiating photochemical reactions that involve ozone-depleting substances (ODS), such as chlorofluorocarbons (CFCs). These reactions lead to the destruction of ozone, resulting in localized ozone holes or areas of reduced ozone concentrations. In the Arctic region, ozone depletion can occur under specific conditions during the polar spring. Here is the key reaction involved in ozone depletion in the Arctic:

$$Cl^{\circ} + O_3 \rightarrow ClO^{\circ} + O_2$$

This reaction involves a chlorine radical (Cl°) reacting with an ozone molecule (O_3) to form a chlorine monoxide radical (ClO°) and an oxygen molecule (O_2). The chlorine monoxide radical can participate in a catalytic cycle that continues the destruction of ozone:

$$ClO^{\circ} + O \rightarrow Cl^{\circ} + O_2$$

In this step, the chlorine monoxide radical (ClO°) reacts with an atomic oxygen (O) to regenerate the chlorine radical (Cl°) and produce another oxygen molecule (O_2). The chlorine radical can then react with more ozone molecules, repeating the process and leading to the destruction of additional ozone molecules. It's important to note that while chlorine is a primary contributor to ozone depletion, other reactive halogen species, such as bromine radicals, can also play a role in the Arctic region. The conditions in the Arctic, such as extremely cold temperatures and the presence of polar stratospheric clouds (PSCs), create an environment conducive to the activation of chlorine and bromine chemistry, leading to enhanced ozone depletion. PSCs provide surfaces for chemical reactions to occur, facilitating the conversion of inactive chlorine and bromine species into reactive forms. The reactions mentioned above represent the primary mechanisms involved in ozone depletion in the Arctic region. These reactions are facilitated by the presence of ozone-depleting substances (ODS), which release chlorine and bromine into the atmosphere. However, it's important to note that the overall ozone depletion in the Arctic is generally less severe compared to the Antarctic ozone hole, which is influenced by different atmospheric dynamics and larger concentrations of ODS.

Climate Change Effects: Climate change is influencing the behavior of ozone in the Arctic. Changing atmospheric circulation patterns and variations in temperatures can impact the transport and distribution of ozone in the region. Additionally, increased emissions of greenhouse gases may indirectly affect ozone chemistry, although the specific interactions are complex and still being studied.

It's worth noting that the Arctic ozone depletion is generally less severe and less persistent compared to the Antarctic ozone hole due to differences in atmospheric dynamics, temperature profiles, and the availability of ozone-depleting substances.

2.5.Free radicals and its role ozone

The role of free radicals in both ozone formation and depletion is significant. Free radicals are highly reactive species that play a crucial role in the complex chemistry of the atmosphere. They participate in various reactions that contribute to the production and destruction of ozone. In this response, I will provide an overview of the role of free radicals in ozone formation and depletion, along with relevant chemical equations and examples.

Ozone Formation:

Ozone formation primarily occurs in the stratosphere, where oxygen molecules (O_2) are split apart by high-energy ultraviolet (UV) radiation, resulting in the formation of free oxygen atoms (O). These free oxygen atoms are highly reactive and can combine with other oxygen molecules to form ozone (O_3). The overall process can be summarized in the following reactions: Photodissociation of Oxygen Molecules:

$$O_2 + UV - C \text{ radiation } \rightarrow 2O$$

In this reaction, UV-C radiation breaks apart an oxygen molecule (O_2) into two oxygen atoms (O).

$$O + O_3 \rightarrow O_2$$

The oxygen atoms (O) produced in the previous step can react with other oxygen molecules (O_2) to form ozone (O_3). This reaction occurs spontaneously and is exothermic.

Free radicals, such as hydroxyl radicals (OH°) and nitric oxide radicals (NO°), also play a role in ozone formation by reacting with oxygen molecules. For example:

Hydroxyl Radical Reaction with Oxygen:

$$OH^{\circ} + O_2 \rightarrow HO_2^{\circ}$$

$$HO_2^{\circ} + O \rightarrow OH^{\circ} + O_2$$

Hydroxyl radicals (OH°) react with oxygen molecules (O_2) to form the hydroperoxyl radical (HO_2°), which can then react with atomic oxygen (O) to regenerate oxygen molecules and produce another hydroxyl radical. This cycle contributes to the overall ozone formation process.

Examples:

The reaction of a hydroxyl radical with an oxygen molecule is an important step in the ozone formation cycle. For instance:

$$OH^{\circ} + O_2 \rightarrow HO_2^{\circ}$$

Nitric oxide radicals (NO°) can also participate in ozone formation. Here is an example reaction:

$$NO^{\circ} + O_2 \rightarrow NO_2^{\circ}$$

$$NO_2^{\circ} + O \rightarrow NO + O_2$$

In this reaction, a nitric oxide radical (NO°) reacts with an oxygen molecule (O_2) to form a nitrogen dioxide radical (NO_2°), which can further react with atomic oxygen (O) to regenerate nitric oxide (NO) and produce another oxygen molecule (O_2).

Ozone Depletion:

Ozone depletion refers to the destruction of ozone molecules in the stratosphere. The primary contributors to ozone depletion are certain reactive substances, such as chlorine and bromine compounds derived from human-made ozone-depleting substances (ODS). Free radicals, particularly chlorine radicals (Cl°) and bromine radicals (Br°), are instrumental in catalytic cycles that lead to ozone destruction. The following reactions exemplify ozone depletion processes:

Chlorine Radical Reaction with Ozone:

$$Cl^{\circ} + O_3 \rightarrow ClO^{\circ} + O_2$$

In this reaction, a chlorine radical (Cl°) reacts with an ozone molecule (O_3), resulting in the formation of a chlorine monoxide radical (ClO°) and an oxygen molecule (O_2). The chlorine monoxide radical can participate in a catalytic cycle that continues the destruction of ozone.

Chlorine Monoxide Radical Reaction with Ozone:

$$ClO^{\circ} + O_3 \rightarrow Cl^{\circ} + 2O_2$$

The chlorine monoxide radical (ClO°) can react with another ozone molecule (O_3), leading to the regeneration of the chlorine radical (Cl) and the production of two oxygen molecules

2.6. Ozone and Climate change

Ozone and climate change are interconnected in several ways. While they are distinct phenomena, changes in one can influence the other. In this response, I will provide an overview of the relationship between ozone and climate change, discussing the effects of climate change on ozone and the impacts of ozone on climate.

Ozone as a Greenhouse Gas:

Ozone itself is a greenhouse gas, albeit a relatively minor one compared to carbon dioxide (CO_2) and methane (CH_4). In the lower atmosphere (troposphere), ozone acts as a greenhouse gas by trapping heat and contributing to the warming of the Earth's surface. However, ozone concentrations in the troposphere are influenced by various factors, including human activities, which can result in both increases and decreases in ozone levels.

Ozone-Depleting Substances (ODS) and Climate Forcing:

Ozone depletion, primarily in the stratosphere, is driven by the release of ozone-depleting substances (ODS), such as chlorofluorocarbons (CFCs) and halons. The destruction of ozone in the stratosphere contributes to cooling of the upper atmosphere, which has implications for climate. The release of ODS not only affects ozone but also has a significant climate forcing effect due to the high global warming potential of these substances. The Montreal Protocol and subsequent agreements have successfully phased out the production and use of ODS, resulting in a positive impact on both ozone depletion and climate change.

Stratospheric Ozone and Atmospheric Circulation:

Changes in stratospheric ozone can influence atmospheric circulation patterns, including the polar jet stream and the position and strength of high and low-pressure systems. These changes in circulation can, in turn, affect weather patterns and climate at the Earth's surface. However, the understanding of the precise linkages between stratospheric ozone and atmospheric circulation is an active area of research.

Climate Change Impacts on Ozone:

Tropospheric Ozone:

Climate change can have implications for tropospheric ozone levels. Elevated temperatures, changes in atmospheric chemistry, and altered atmospheric circulation patterns associated with climate change can affect the formation and concentration of tropospheric ozone. Rising temperatures can increase the chemical reactions that produce ozone, leading to higher concentrations in certain regions. Additionally, changes in atmospheric circulation can influence the transport and distribution of ozone precursors, such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), contributing to changes in tropospheric ozone levels.

Stratospheric Ozone Recovery:

The recovery of stratospheric ozone from depletion is also influenced by climate change. Changes in temperature and water vapor content in the stratosphere due to increasing greenhouse gas concentrations can affect the chemical reactions involved in ozone depletion and recovery. For example, the cooling of the stratosphere due to increased greenhouse gases can enhance the formation of polar stratospheric clouds (PSCs), which provide surfaces for chemical reactions that facilitate ozone depletion.

Impacts of Ozone on Climate:

Radiative Forcing:

Ozone, both in the troposphere and stratosphere, contributes to radiative forcing, which is the perturbation of Earth's energy balance. In the stratosphere, the presence or depletion of ozone affects the amount of ultraviolet (UV) radiation reaching the Earth's surface. In the troposphere, ozone acts as a greenhouse gas and contributes to the absorption and emission of infrared radiation, thereby influencing the Earth's energy budget.

Feedback Effects:

Changes in ozone can lead to feedback effects on climate. For instance, stratospheric ozone depletion can result in cooling of the stratosphere,

2.7. Ozone and Dobson unit

Ozone is a molecule composed of three oxygen atoms (O_3) and is present in the Earth's atmosphere. It plays a crucial role in absorbing harmful ultraviolet (UV) radiation from the Sun, protecting life on Earth. Ozone is primarily found in the stratosphere, a layer of the atmosphere located between approximately 10 to 50 kilometers above the Earth's surface. The Dobson unit (DU) is a unit of measurement used to quantify the total amount of ozone in a vertical column of the atmosphere. It is named after G.M.B. Dobson, who was a pioneer in the field of atmospheric ozone research. The Dobson unit represents the thickness of an ozone layer that would be obtained if all the ozone in a column of air were brought to the Earth's surface and spread out uniformly. The concept of the Dobson unit is based on the fact that the concentration of ozone in the stratosphere is relatively low compared to other atmospheric gases. It is typically measured in parts per million (ppm) or milligrams per cubic meter (mg/m^3). However, these concentration measurements can vary with altitude and temperature. Therefore, using the Dobson unit provides a standardized measurement that represents the total amount of ozone in a vertical column. To measure ozone in Dobson units, instruments called spectrophotometers are used. These instruments measure the intensity of sunlight at different wavelengths as it passes through the Earth's atmosphere. By analyzing the variation in sunlight intensity, scientists can determine the ozone concentration and calculate the Dobson units. Typically, the average ozone concentration in the atmosphere is around 300 Dobson units. Higher values are observed in regions with less pollution and lower values in areas affected by ozone depletion or pollution. The ozone hole, a significant depletion of ozone over Antarctica during the Southern Hemisphere's spring, is often reported in negative Dobson units, indicating a reduction in ozone concentration compared to the average. Monitoring ozone levels in Dobson units is crucial for assessing the health of the ozone layer, tracking changes in ozone concentrations, and studying ozone depletion and recovery processes. It provides valuable information for understanding the impacts of human activities and natural processes on the ozone layer and helps in formulating policies and regulations to protect this vital atmospheric component.

2.8. Global warming potential

Global warming potential (GWP) is a measure used to compare the greenhouse warming effects of different greenhouse gases (GHGs) over a specific time period, usually 100 years. It quantifies the relative ability of a particular GHG to trap heat in the atmosphere compared to carbon dioxide ($\mathrm{CO_2}$), which is often used as a reference gas with a GWP of 1. The GWP takes into account both the radiative properties of the gas and its atmospheric lifetime. It considers the amount of heat that a gas can trap in the atmosphere and how long it persists in the atmosphere before being removed. The higher the GWP of a gas, the more potent it is as a contributor to global warming. For example, methane ($\mathrm{CH_4}$) has a higher GWP than $\mathrm{CO_2}$because it is a more effective greenhouse gas, trapping more heat. Over a 100-year time frame, methane has a GWP of approximately 25, meaning it has 25 times the warming potential of $\mathrm{CO_2}$. Nitrous oxide ($\mathrm{N_2O}$) has a GWP of about 298, making it a much more potent greenhouse gas than $\mathrm{CO_2}$. he GWP values are determined through scientific assessments based on the best available knowledge of the greenhouse gas's properties and atmospheric behavior. These values are used in various environmental and policy contexts to assess the climate impact of different emissions and to develop strategies for mitigating global warming.

2.9. Green house potential of various gases:

Here are the global warming potentials (GWPs) for some common greenhouse gases (GHGs) over a 100-year time horizon:

Carbon dioxide (CO_2): GWP = 1

Methane (CH_4): GWP = 25

Nitrous oxide (N_2O): GWP = 298

Hydrofluorocarbons (HFCs):

HFC-23: GWP = 12,000

HFC-32: GWP = 675

HFC-134a: GWP = 1,430

HFC-152a: GWP = 124

HFC-143a: GWP = 3,780

Perfluorocarbons (PFCs):

PFC-14 (CF_4): GWP = 7,390

PFC-116 (C_2F_6): GWP = 12,200

PFC-218 (C_3F_8): GWP = 8,830

PFC-318 (C_4F_{10}): GWP = 9,200

Sulfur hexafluoride (SF_6): GWP = 23,500

Please note that these values are approximate and can vary slightly depending on the assessment and the time horizon considered. The GWPs are used to compare the warming potential of different gases relative to carbon dioxide, which is assigned a GWP of 1 as the reference gas.

Ozone potential of greenhouse gases

The ozone potential of greenhouse gases refers to their ability to affect the concentration of ozone in the Earth's atmosphere. Greenhouse gases can both directly and indirectly influence ozone concentrations through various chemical reactions. Here are some examples of greenhouse gases and their ozone potentials:

Carbon Dioxide (CO_2):

Carbon dioxide is a well-known greenhouse gas that contributes to global warming and climate change. While it does not directly deplete ozone, increasing CO_2concentrations can indirectly impact ozone levels through changes in atmospheric temperatures and circulation patterns.

Methane (CH_4):

Methane is another significant greenhouse gas. It does not directly deplete ozone but can influence ozone concentrations indirectly. Methane can react with hydroxyl radicals (OH) in the atmosphere, reducing the availability of OH radicals that are involved in the breakdown of ozone.

Nitrous Oxide (N_2O):

Nitrous oxide is both a greenhouse gas and a minor ozone-depleting substance. It has a small direct ozone depletion potential (ODP) but plays a more substantial role in indirectly affecting ozone levels. N_2Ocan react with ozone in the stratosphere, catalytically destroying it and leading to a reduction in ozone concentrations.

Chlorofluorocarbons (CFCs):

CFCs are synthetic compounds that were widely used in the past in various applications, including refrigeration, air conditioning, and aerosol propellants. They have significant ozone depletion potentials (ODPs) and were major contributors to the depletion of the ozone layer. CFCs can undergo photodissociation in the stratosphere, releasing chlorine atoms that can catalytically destroy ozone molecules.

Hydrochlorofluorocarbons (HCFCs):

HCFCs are transitional compounds used as replacements for CFCs due to their lower ODPs. They still have some ozone depletion potential and contribute to ozone depletion, although to a lesser extent than CFCs. HCFCs can also release chlorine atoms in the stratosphere, leading to ozone destruction.

The ozone potential of greenhouse gases is different from their greenhouse warming potential (GWP), which quantifies their ability to trap heat in the atmosphere and contribute to global warming. The two factors, ozone potential and greenhouse warming potential, are distinct and are assessed separately when evaluating the environmental impact of different gases. The chemical equations for the reactions involving greenhouse gases and ozone are complex and involve multiple steps. The reactions can vary depending on the specific greenhouse gas and the atmospheric conditions. However, the examples provided above capture the general impacts of greenhouse gases on ozone concentrations.

2.10. Montreal protocol

In the 1970s, scientific research highlighted the damaging effects of ODS, particularly chlorofluorocarbons (CFCs), on the ozone layer. The depletion of the ozone layer was shown to increase harmful ultraviolet (UV) radiation reaching the Earth's surface, leading to concerns about the potential impacts on human health, ecosystems, and climate. The Montreal Protocol is an international environmental treaty designed to protect the ozone layer by phasing out the production and use of ozone-depleting substances (ODS).

In September 1987, the Montreal Protocol on Substances that Deplete the Ozone Layer was agreed upon and signed by countries. The Protocol laid out a comprehensive strategy to reduce and eliminate the production and consumption of ODS.

The Montreal Protocol initially targeted ODS, including chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform. These substances were widely used in various industrial applications such as refrigeration, air conditioning, aerosols, and foam-blowing agents.

Over the years, the Montreal Protocol has undergone several amendments and adjustments to accelerate the phase-out of ODS. Subsequent adjustments added other substances, such as hydrochlorofluorocarbons (HCFCs), which are less harmful than CFCs but still contribute to ozone depletion. Additionally, the Kigali Amendment in 2016 introduced a phase-down schedule for hydrofluorocarbons (HFCs), potent greenhouse gases used as substitutes for ODS.

The Montreal Protocol has achieved significant success in reducing the production and consumption of ODS. As of the knowledge cutoff in September 2021, global production and consumption of major ODS have been reduced by more than 98%. This achievement has been possible through the development and adoption of alternative technologies and substances that have lower or no ozone-depleting potential.

As a result of the Montreal Protocol's efforts, the ozone layer is showing signs of recovery. The concentrations of many ODS in the atmosphere have been declining, and the stratospheric ozone layer is projected to recover to pre-1980 levels by the middle of this century.

The Montreal Protocol has enjoyed widespread participation and compliance from nations worldwide. Currently, nearly every country in the world has ratified the Protocol, demonstrating a global commitment to ozone protection.

Despite significant achievements, challenges remain in fully phasing out ODS, ensuring compliance, and addressing emerging issues. The phase-down of HFCs under the Kigali Amendment is a critical ongoing effort to mitigate their environmental impact. the Montreal Protocol has played a pivotal role in addressing ozone depletion through international cooperation and coordinated action. It has achieved remarkable success in reducing the production and consumption of ODS, leading to the recovery of the ozone layer. Ongoing efforts are focused on continued compliance, addressing remaining challenges, and responding to emerging ozone-related concerns.

2.10.1. Montreal protocol agreement

The Montreal Protocol is a global environmental agreement, and virtually all countries in the world are involved as parties to the agreement. As of the knowledge cutoff in September 2021, there are 198 parties to the Montreal Protocol. These include 197 countries (including all United Nations member states) and the European Union as a regional economic integration organization.

The Montreal Protocol is an international environmental agreement that aims to protect the ozone layer by phasing out the production and consumption of ozone-depleting substances (ODS). The primary objective of the Montreal Protocol is to protect the ozone layer, which shields the Earth from harmful ultraviolet (UV) radiation. The agreement seeks to control and reduce the production and use of ODS, which are substances responsible for the depletion of ozone in the stratosphere.

The broad participation of countries in the Montreal Protocol reflects the global recognition of the need to protect the ozone layer and address the depletion of ozone-depleting substances (ODS). The agreement's universal membership signifies the commitment of nations worldwide to cooperate and take action to phase out ODS and promote the recovery of the ozone layer.

Commitments and Control Measures:

Q.1. Production and Consumption Control:

The Montreal Protocol sets mandatory control measures to regulate the production and consumption of ODS. Parties to the agreement commit to phasing out the production and use of specific ODS in a specified timeframe.

Q.2. Ozone Depletion Potential (ODP):

The Protocol uses the concept of Ozone Depletion Potential (ODP) to measure the ozone-depleting effects of different substances. Each ODS is assigned an ODP value, indicating its potential to deplete ozone relative to the reference substance, CFC-11.

Q.3. Multilateral Fund:

The agreement established the Multilateral Fund for the Implementation of the Montreal Protocol, which provides financial and technical assistance to developing countries to support their compliance with the Protocol's requirements.

Amendments and Adjustments:

The Montreal Protocol has undergone several amendments and adjustments to strengthen control measures and address emerging issues related to ozone depletion. Notable amendments include the London Amendment (1990), the Copenhagen Amendment (1992), the Montreal Amendment (1997), and the Beijing Amendment (1999). These amendments accelerated the phase-out of ODS and expanded the scope of controlled substances.

Compliance and Reporting:

Parties to the Montreal Protocol are required to report regularly on their ODS production, consumption, and control measures. The reporting ensures transparency and facilitates the monitoring of progress towards phasing out ODS.

Technology Transfer and Capacity Building:

The Protocol recognizes the importance of technology transfer and capacity building to support developing countries in their efforts to comply with the control measures. It encourages developed countries to assist developing countries in implementing ODS phase-out programs and adopting environmentally friendly alternatives.

Meetings of the Parties:

The Parties to the Montreal Protocol hold regular meetings to review progress, discuss scientific and technical issues, make decisions on amendments, and provide guidance on the implementation of control measures.

Kigali Amendment:

The Kigali Amendment, adopted in 2016, is a significant addition to the Montreal Protocol. It addresses hydrofluorocarbons (HFCs), potent greenhouse gases used as replacements for ODS. The Kigali Amendment introduces a phase-down schedule for HFCs to mitigate their contribution to climate change, while promoting the use of low-global-warming-potential alternatives.

Overall, the Montreal Protocol is considered one of the most successful international environmental agreements. It has led to significant reductions in ODS production and consumption, resulting in the recovery of the ozone layer. The agreement demonstrates the effectiveness of global cooperation in addressing environmental challenges and serves as a model for future international environmental efforts.

2.10.2. Role of India in Montreal protocol agreement

India has played a significant role in the Montreal Protocol agreement, actively participating in its implementation and making significant contributions to the protection of the ozone layer. Ratification and Compliance:

India ratified the Montreal Protocol on November 19, 1992, showcasing its commitment to the global efforts of ozone layer protection. As a party to the agreement, India has complied with its obligations, including reporting on ODS production and consumption, implementing control measures, and taking steps towards the phase-out of ODS.

ODS Phase-out Initiatives:

India has undertaken various initiatives and programs to phase out ozone-depleting substances (ODS) within the country. The country has successfully reduced the production and consumption of ODS, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), through regulatory measures and promotion of alternative technologies.

Multilateral Fund Support:

India has received financial and technical assistance from the Multilateral Fund for the Implementation of the Montreal Protocol. This support has helped India in implementing projects and programs aimed at phasing out ODS, capacity building, technology transfer, and promoting the use of environmentally friendly alternatives.

Technology Development and Transfer:

India has been actively involved in the development and transfer of ozone-friendly technologies. The country has invested in research and development of alternative substances and technologies that have lower or no ozone-depleting potential. India has also shared its experiences and knowledge with other developing countries to facilitate their transition to ozone-safe technologies.

Industry Engagement:

India has engaged with various industries and stakeholders to promote the adoption of ozone-friendly alternatives. The government has collaborated with manufacturers, importers, and associations to raise awareness, provide training, and ensure the availability of alternative technologies and products that comply with the Montreal Protocol requirements.

Global Cooperation:

India actively participates in meetings and discussions under the Montreal Protocol framework. The country contributes to policy deliberations, scientific assessments, and decision-making processes to strengthen the effectiveness of the agreement. India's active engagement promotes global cooperation and encourages other countries to fulfill their obligations under the Montreal Protocol.

Ozone Layer Monitoring:

India has established a robust network for monitoring the ozone layer and its depletion. The Indian Space Research Organization (ISRO) operates satellite-based ozone monitoring instruments that provide valuable data on ozone concentrations and trends. This monitoring helps in assessing the effectiveness of control measures and evaluating the recovery of the ozone layer.

India's involvement in the Montreal Protocol demonstrates its commitment to environmental sustainability and global cooperation. The country's efforts in phasing out ODS, technology development, capacity building, and active engagement contribute to the collective global endeavor of protecting the ozone layer and mitigating the impacts of ozone depletion.

9.11. Smog

The smog is a general term referring to air pollution which constituents of solid particles and or liquid aerosols. Smog is a type of air pollution characterized by a mixture of smoke and fog, typically resulting from the interaction of pollutants in the atmosphere. Smog formation involves complex chemical reactions, primarily driven by the presence of pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs). Here is an overview of smog formation and depletion, along with examples from around the world and India:

Smog Formation:

Smog formation involves both primary and secondary pollutants, as well as various chemical reactions. The primary contributors to smog formation are:

Nitrogen Oxides (NO_x):

NO_xcompounds, primarily nitrogen dioxide (NO_2),are released from combustion processes in vehicles, power plants, and industrial activities. In the presence of sunlight, NO_2 can undergo photolysis, leading to the formation of free radicals.

Volatile Organic Compounds (VOCs):

VOCs are released from various sources, including industrial emissions, vehicle exhaust, and chemical solvents. Examples of VOCs include benzene, toluene, and formaldehyde. VOCs can react with sunlight and other pollutants to form secondary pollutants.

The chemical reactions involved in smog formation are complex and often occur in the presence of sunlight. Some of the key reactions include:

Photochemical Oxidation:

NO_2 can undergo photolysis in the presence of sunlight, resulting in the formation of nitrogen monoxide (NO) and atomic oxygen (O). These free radicals can react with VOCs, initiating a series of chain reactions known as photochemical oxidation. The reactions produce ozone (O_3) and other secondary pollutants such as peroxyacetyl nitrate (PAN).

Peroxyacetyl nitrate (PAN)

Peroxyacetyl nitrate (PAN) is a secondary pollutant that forms in the atmosphere as a result of photochemical reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NO_x). It is an important component of photochemical smog and is considered harmful to both human health and the environment.

Formation of Peroxyacetyl Radicals$CH_3C(O)O_2$:

VOCs, such as ethane (C_2H_6), react with hydroxyl radicals (OH) in the presence of nitrogen dioxide (NO_2) to form peroxyacetyl radicals:

$$C_2H_6 + OH \rightarrow CH_3C(O)O_2 + H_2O$$

Reaction of Peroxyacetyl Radicals with Nitric Oxide (NO):

The peroxyacetyl radicals $CH_3C(O)O_2$react with nitric oxide (NO) to form peroxyacetyl nitrate (PAN) and nitrogen dioxide (NO_2):

$$CH_3C(O)O_2 + NO \rightarrow PAN + NO_2$$

The formation of PAN is most significant in areas with high levels of VOCs and NOx emissions, such as urban and industrial areas. Sunlight plays a crucial role in driving the photochemical reactions that lead to the production of PAN.

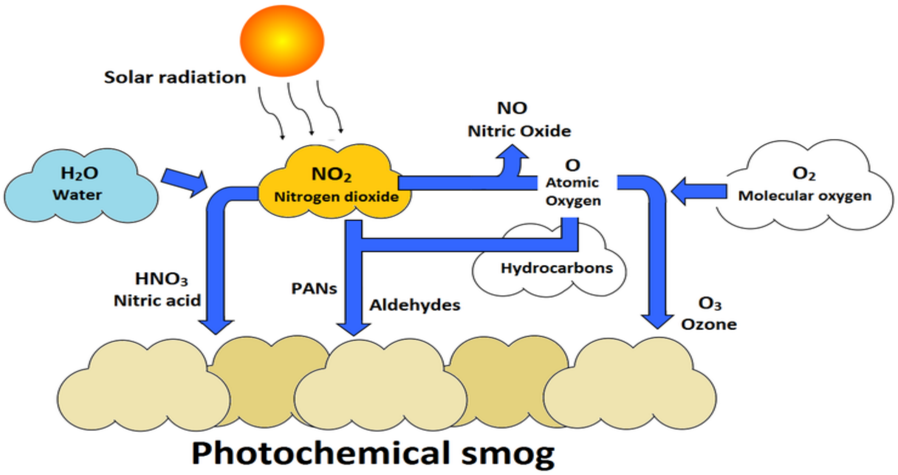
PAN is a strong respiratory irritant and can cause eye and throat irritation, coughing, and shortness of breath in humans. It can also contribute to the formation of ground-level ozone and smog, further exacerbating air pollution issues. PAN is involved in the transport and long-range dispersion of NOx and VOCs. It can act as a reservoir for NO_x, releasing it in remote regions and contributing to ozone formation away from emission sources. The control of PAN and other smog-forming pollutants requires the reduction of VOC and NO_x emissions through stricter regulations, improved industrial processes, and the use of cleaner technologies. The monitoring and understanding of PAN levels in the atmosphere are crucial for assessing air quality, evaluating the effectiveness of pollution control measures, and implementing strategies to mitigate its harmful effects.

Examples of Smog Formation and Depletion:

Delhi Smog: Delhi, the capital city of India, has experienced severe smog episodes in recent years, especially during the winter months. The smog in Delhi is primarily attributed to emissions from vehicles, biomass burning, industrial activities, and agricultural practices. High levels of pollution, combined with weather conditions like temperature inversions, contribute to the formation and persistence of smog. The government has implemented various measures to control emissions, including the introduction of cleaner fuel standards and the implementation of the odd-even vehicle scheme to reduce traffic congestion.

9.11.1. Los Angeles Smog:

The smog in Los Angeles, known as Los Angeles-type smog or photochemical smog, is primarily caused by the interaction of sunlight with pollutants emitted from vehicle exhaust, industrial emissions, and other sources. Los Angeles in California occur air pollution during 1944, it characterized by reducing visibility, eye irritation and plant damage etc. While there is no single chemical equation that captures the entire complex process of Los Angeles smog formation, several key reactions contribute to its formation. Here are some important reactions and factors involved.



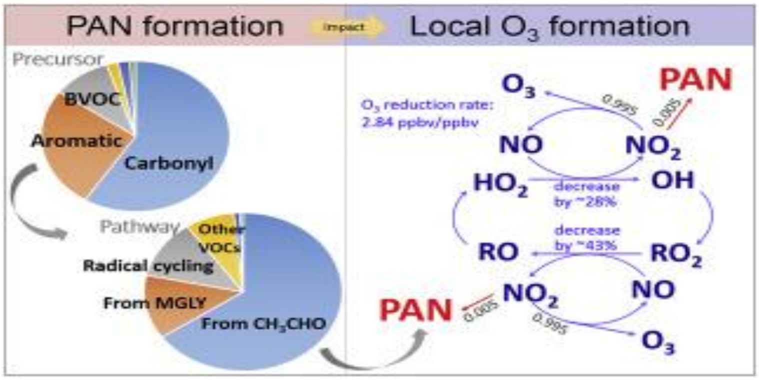
Source: Photochemical smog - Energy Education

Nitrogen OxidesNO_x Emissions:

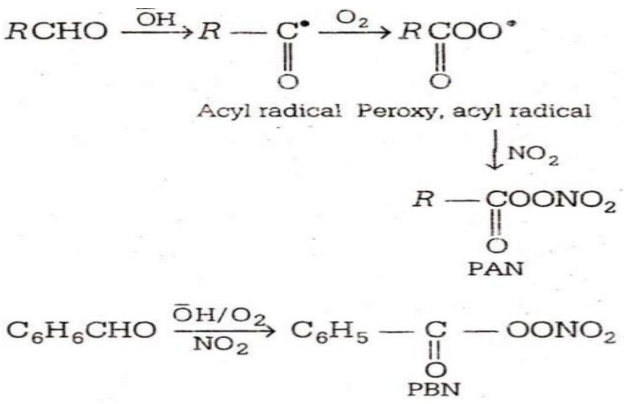
Vehicles and industrial activities release nitrogen oxides (NO_x), primarily nitrogen dioxide (NO_2), into the atmosphere. The combustion of fossil fuels contributes to these emissions. The reaction for the formation of nitrogen dioxide is:

$$N_2 + O_2 \rightarrow 2NO$$

$$2NO + O_2 \rightarrow NO_2$$



Formation of smog form Reactive hydrocarbon or from vehicle is such as



Photochemical Oxidation:

In the presence of sunlight, nitrogen dioxide (NO_2) can undergo photolysis, leading to the formation of nitrogen monoxide (NO) and atomic oxygen (O):

$$NO_2 + \text{sunlight} \rightarrow NO + O$$

The free radicals NO and O can then react with volatile organic compounds (VOCs) to initiate a series of chain reactions known as photochemical oxidation. These reactions produce ozone (O_3), peroxyacetyl nitrate (PAN), and other secondary pollutants.

9.11.2. London smog:

The Great Smog of London, also known as the London smog or the Big Smoke, occurred in December 1952 and was one of the deadliest air pollution episodes in history. The smog was primarily caused by the combustion of coal and the release of pollutants into the atmosphere. Although there were no specific chemical equations responsible for the entire event, several reactions played a role in the formation of the smog. Here are some key reactions and factors involved:

Sulfur Dioxide (SO_2) Emissions:

Burning coal in residential and industrial areas released large amounts of sulfur dioxide (SO_2) into the air. The chemical equation for the combustion of coal can be represented as:

$$C + O_2 \rightarrow CO_2$$

$$S + O_2 \rightarrow SO_2$$

Formation of Sulfuric Acid (H_2SO_4):

In the presence of sunlight, sulfur dioxide (SO_2) reacted with oxygen (O_2) and water vapor (H_2O) to form sulfuric acidH_2SO_4:

$$2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4$$

Nitrogen Dioxide (NO_2) Emissions:

The combustion of coal and other fossil fuels released nitrogen dioxide (NO2) into the atmosphere. The equation for the formation of nitrogen dioxide is:

$$N_2 + O_2 \rightarrow 2NO$$

$$2NO + O_2 \rightarrow 2NO_2$$

Effect of photochemical smog:

Ozone and PAN caused irritation of eye and respiration tract trouble. Lower concentration of ozone causes non-lethal accumulation of fluid in the lungs and can damage the lung capabilities.

NO_2produced nose and eye irritation and pulmonary discomfort. Lower concentration of O_3 irritates the nose and thought while its higher concentration cause headache, cough, dryness of the throat, chest pain, difficulties in breathing etc. Ozone together with PAN form small drops in air forming smog, thus blanketing the sunshine which inhibits the role of photosynthesis in plants. These oxidants (O_3 and PAN) have also been found to inhibit the activity of enzymes that are responsible for the synthesis of cellulose and lipids in plants. Ozone also causes cracknels and damage in rubber in fabrics.

Control of photochemical pollutants:

The control of primary pollutants such asNO_x, $SO_x$with alternating control O_3 and PAN, which are secondary pollutants. NO_x can control by

a. Decreasing the flame temperature by engientic water and stream.
b. Tow stage combustion process has been suggested to remove NO_x, i) the fuel is fire at high temperature, ii) partial cooling and excess of air is injected with greater than stoichiomertic air fuel ratio.
c. To remove NO_x formation by catalytic decomposition

Photochemical pollutants, also known as ground-level ozone and smog, are harmful air pollutants that result from complex chemical reactions involving sunlight, volatile organic compounds (VOCs), and nitrogen oxides (NOx). These pollutants have detrimental effects on human health, ecosystems, and the environment. Effective control measures are essential to mitigate the impact of photochemical pollutants. This article discusses various strategies to control ground-level ozone and smog.

1. Reducing Emissions:

Reducing the emissions of precursor pollutants, particularly VOCs and NOx, is a primary method of controlling photochemical pollutants. This can be achieved through regulations, technology improvements, and public awareness.

a. Tailpipe Emissions: Regulations and standards for vehicle emissions play a crucial role in controlling NOx and VOC emissions. The adoption of cleaner vehicle technologies, such as catalytic converters and electric vehicles, has been effective in reducing emissions from automobiles.

b. Industrial Emissions: Regulations on industrial processes and emissions have helped limit the release of VOCs and NOx from manufacturing, energy production, and other sources. Technologies like selective catalytic reduction and flue gas desulfurization are used to reduce emissions from power plants.

2. Promoting Clean Energy:

Transitioning to clean and renewable energy sources reduces emissions of both VOCs and NOx. Solar, wind, and hydropower, as well as energy efficiency measures, are instrumental in reducing the reliance on fossil fuels, which are significant sources of photochemical pollutants.

3. Urban Planning and Transportation:

Efficient urban planning and public transportation systems can reduce vehicle emissions and thereby mitigate photochemical pollution.

a. Public Transportation: Expanding and improving public transportation systems can encourage people to use cars less frequently, reducing overall emissions of VOCs and NOx.

b. Urban Green Spaces: Increasing green spaces in cities can help absorb pollutants and improve air quality.

4. VOC Control:

VOCs are a major contributor to photochemical pollution. Therefore, controlling and reducing VOC emissions are essential. Strategies include:

a. Solvent Management: Implementing regulations on solvent usage in various industries, such as painting and printing, helps control VOC emissions.

b. Emission Reduction Technologies: Installing VOC control technologies like vapor recovery systems in industries can capture and recycle VOC emissions.

5. NOx Control:

Reducing NOx emissions is equally critical. Strategies include:

a. Combustion Controls: Optimizing combustion processes in power plants and industrial facilities can minimize NOx emissions.

b. Catalytic Converters: These devices, commonly used in automobiles, help reduce NOx emissions by converting them into less harmful compounds.

6. Emission Monitoring and Compliance:

Monitoring and enforcing compliance with emission standards is vital for the effectiveness of control measures. Regular inspections and penalties for non-compliance encourage industries and individuals to adhere to regulations.

7. Public Awareness:

Educating the public about the sources and health impacts of photochemical pollutants is essential. This awareness can lead to more responsible choices and support for pollution control measures.

8. Regional and International Cooperation:

Since air pollution can travel across borders, regional and international collaboration is crucial. Agreements and protocols, such as the Clean Air Act in the United States and the Gothenburg Protocol in Europe, have been successful in reducing transboundary air pollution.

9. Research and Innovation:

Continued research and technological innovation are essential for the development of more effective and efficient control measures. This includes exploring new catalysts, emission control technologies, and alternative fuels.

In conclusion, photochemical pollutants, such as ground-level ozone and smog, pose significant health and environmental challenges. To control these pollutants effectively, a combination of strategies is necessary, including emission reductions, clean energy adoption, urban planning, and public awareness. Collaborative efforts at the local, national, and international levels are key to mitigating the impact of photochemical pollutants and improving air quality for all.

9.12. Summary

Ozone (O_3) is a molecule composed of three oxygen atoms. It plays a vital role in both the Earth's upper atmosphere and the lower atmosphere. While ozone in the stratosphere acts as a protective shield against harmful ultraviolet (UV) radiation, ozone in the lower atmosphere, known as tropospheric ozone, contributes to the formation of photochemical smog. tropospheric ozone is primarily formed through complex chemical reactions involving nitrogen oxides (NO_x), volatile organic compounds (VOCs), and sunlight. These reactions occur in the presence of specific atmospheric conditions. NO_x are produced through natural processes, such as lightning, as well as human activities like the burning of fossil fuels. Nitric oxide (NO) is the primary nitrogen oxide emitted. Once in the atmosphere, NO is further oxidized to nitrogen dioxide (NO_2) through reactions with other compounds. VOCs are organic chemicals that easily evaporate at normal temperatures. They are emitted by sources such as industrial processes, vehicles, solvents, and vegetation. Examples of VOCs include benzene, toluene, and formaldehyde. The combination of tropospheric ozone and other secondary pollutants leads to the formation of photochemical smog. Photochemical smog is a mixture of pollutants that affects air quality and human health. It is characterized by a hazy appearance, a distinctive odor, and reduced visibility. Smog formation is more likely on warm, sunny days with stagnant air masses that trap pollutants close to the surface. High levels of $NO_x$and VOC emissions increase the potential for smog formation. Photochemical smog contains other pollutants. These include nitrogen dioxide (NO_2), particulate matter (PM), volatile organic compounds (VOCs), and various other secondary pollutants. PM and VOCs contribute to respiratory issues, eye irritation, and reduced lung function.

9.13. Terminal questions

Q.1. What is Atmospheric ozone; discuss the ozone formation and depletion of ozone.

Answer: --

Q.2. Discus the nature of stratospheric ozone and its role to protect human health.

Answer: --

Q.3. Discuss the role of free radicals in ozone depletion.

Answer: --

Q.4. Discuss the ozone and climate change with examples.

Answer: --

Q.5. Discuss about Montreal protocol and its agreement.

Answer: --

Q.6. What is smog? Discuss the London and Los Angeles smog.

Answer: --

9.14.Further suggested readings

1. Environmental Science, Subhas Chandra Santra, new central book agency, 3rd Edition, 2011
2. A text Book of Environment Studies, Asthana, D.K. and Asthana, M. 2006, S. Chand & Co
3. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd
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Unit-3: Sampling and Air Pollution Abatement

Contents

3.1. Introduction

Air sampling is a crucial technique used to collect and analyze air samples for various purposes, including environmental monitoring, occupational health and safety assessments, indoor air quality investigations, and scientific research. It involves the collection of air samples from specific locations or sources to identify and quantify the presence of various contaminants, such as particulate matter, gases, vapors, and microorganisms. Determine the purpose of the air sampling, such as identifying potential pollutants or assessing compliance with air quality standards. Plan the sampling strategy, including the locations, duration, and frequency of sampling. Choose an appropriate sampling method based on the contaminants of interest and the specific objectives. Common air sampling techniques include grab sampling, passive sampling, and active sampling. Analyze the collected air samples using appropriate techniques to quantify the contaminants of interest. The analysis may involve various methods, such as gravimetry, chromatography, spectrometry, or microbiological assays. The choice of method depends on the specific pollutants being investigated. Evaluate the analytical results in light of the sampling objectives. Compare the obtained concentrations with relevant standards, guidelines, or baseline values. Interpret the data to identify trends, sources of contamination, or potential health risks. Prepare a comprehensive report summarizing the sampling methodology, results, and conclusions. Proper air sampling techniques are essential to ensure accurate and reliable results. Quality control measures, including proper calibration of sampling equipment, adherence to standardized protocols, and adherence to safety guidelines, should be followed throughout the process. This helps to maintain the integrity of the samples and ensures the validity of the data collected.

Objectives

- To discuss the various sampling methods of gases
- To discuss the adsorption and absorption of gases
- To discuss the types of particulate matter and their collection equipment
- To discuss how to control the particulate matter

3.2. Sampling of gaseous pollutants

Sampling of gaseous pollutants involves the collection and analysis of air samples to identify and quantify the presence of specific gases or vapors in the atmosphere. Gaseous pollutants can arise from various sources, such as industrial emissions, vehicle exhaust, combustion processes, or natural sources. Here are some commonly used techniques for sampling gaseous pollutants:

Passive Sampling:

Diffusion Tubes: These are commonly used for long-term monitoring of certain gases, such as nitrogen dioxide (NO_2) or sulfur dioxide (SO_2). The diffusion tube contains a reactive substance that captures the targeted gas over time. The amount of gas absorbed is measured later in the laboratory.

Sorbent Tubes: These tubes are filled with solid or liquid sorbents that capture specific gases. When air passes through the tube, the targeted gas molecules are adsorbed onto the sorbent material. Sorbent tubes are often used for short-term or grab sampling and can be analyzed using thermal desorption techniques.

Active Sampling:

Canisters: Stainless steel or glass canisters with a known volume are used to collect air samples. They are equipped with valves to control the sampling duration. Canisters are commonly used for the analysis of volatile organic compounds (VOCs) and other gases. Once the sample is collected, it is usually analyzed using gas chromatography (GC) or mass spectrometry (MS) techniques.

Tedlar Bags: These are flexible bags made of Tedlar® film, which is chemically inert and does not react with most gases. Tedlar bags are convenient for collecting large-volume air samples, especially when immediate analysis is required. However, they are typically used for qualitative assessments rather than quantitative measurements.

Direct-Reading Instruments:

Real-time or direct-reading instruments are used for immediate, on-site measurements of specific gases.These portable devices provide instant information about gas concentrations and can be useful for rapid screening or preliminary assessments. Examples include photoionization detectors (PIDs) for volatile organic compounds and electrochemical sensors for gases like carbon monoxide (CO) or ozone (O_3).Proper sampling techniques are essential to obtain accurate and representative results when dealing with gaseous pollutants. Factors such as sampling location, sampling duration, flow rates, and equipment calibration should be carefully considered. It is also important to account for potential interferences, such as cross-sensitivities, when selecting and interpreting the analytical methods used for gas analysis.

Following the sampling process, the collected samples are usually analyzed in a laboratory using appropriate techniques, such as gas chromatography (GC), mass spectrometry (MS), or infrared spectroscopy, depending on the specific gases being targeted. The analytical results are then interpreted in relation to relevant standards, guidelines, or regulations to assess air quality and potential health risks associated with the gaseous pollutants.

3.3. Adsorption and adsorption of gaseous pollutants

Adsorption and absorption are two distinct processes related to the interaction of gases with solid or liquid surfaces. Here's an explanation of both terms in the context of gaseous pollutants:

3.3.1. Adsorption:

Adsorption refers to the process in which gas molecules adhere to the surface of a solid or liquid. When gaseous pollutants come into contact with a solid material (known as an adsorbent), they can adhere to the surface through various intermolecular forces, such as van der Waals forces or electrostatic interactions. The adsorbed molecules remain on the surface rather than being absorbed into the bulk of the material.Adsorption is commonly used as a method for capturing and removing gaseous pollutants from air or gas streams. For example, activated carbon is often employed as an adsorbent material due to its high surface area and adsorption capacity. The gas molecules are attracted to the carbon surface and become attached to it, effectively removing them from the surrounding air or gas mixture. This technique is widely used in air purification systems, gas masks, and industrial processes to mitigate the presence of pollutants.

Adsorption is a process by which gas molecules adhere to the surface of a solid material, forming a thin film or layer. This method is commonly used for gas separation and purification, as well as for gas storage and sensing applications. There are several adsorption techniques employed for gas adsorption, including the following:

a) **Activated Carbon Adsorption**:

Activated carbon is a highly porous material with a large surface area that can absorb a wide range of gases. It is commonly used for air and water purification, as well as in gas masks and respirators. Gas molecules are adsorbed onto the surface of the activated carbon due to weak van der Waals forces.

b) **Molecular Sieve Adsorption**:

Molecular sieves are crystalline materials with uniform-sized pores. They are designed to selectively adsorb certain gas molecules based on their size and shape. This technique is often used for separating gases in industrial processes such as natural gas purification and air separation.

c) Zeolite Adsorption:

Zeolites are another type of crystalline material with a porous structure. They have a high affinity for adsorbing water and certain gases such as carbon dioxide and nitrogen. Zeolites find applications in gas drying, gas separation, and catalysis.

d) Silica Gel Adsorption:

Silica gel is a porous form of silicon dioxide that is commonly used as a desiccant for moisture control. It can also adsorb certain organic compounds and gases. Silica gel is often found in small packets in product packaging to prevent moisture damage.

e) Metal-Organic Frameworks (MOFs):

MOFs are a class of materials composed of metal ions or clusters coordinated with organic ligands. They exhibit high porosity and large surface areas, making them suitable for gas storage and separation. MOFs can be tailored to adsorb specific gases by choosing appropriate metal-ligand combinations.

There isn't a single formula that universally represents the adsorption process for gases, as it can be influenced by various factors and mechanisms. However, there are some common mathematical models and equations that describe specific aspects of gas adsorption. Here are a few examples:

i. **Langmuir Adsorption Isotherm**: The Langmuir model is a commonly used equation to describe the adsorption of gases onto a solid surface. It assumes a monolayer adsorption process where gas molecules adsorb onto available sites on the surface. The Langmuir equation is given by:

$$\theta = (K^*P)/(1 + K^*P)$$

where θ is the fractional coverage of the surface, K is the Langmuir constant related to the adsorption affinity, and P is the pressure of the gas.

ii. **BET Adsorption Isotherm**: The Brunauer-Emmett-Teller (BET) model is a more sophisticated equation that considers multilayer adsorption on a solid surface. It takes into account the formation of multiple layers of adsorbed gas molecules. The BET equation is given by:

$$P / (V * (P_0 - P)) = (1 / (V * P_0)) * ((1 - \theta) / \theta) * (C - 1)$$

where P is the equilibrium pressure, V is the gas adsorbed volume, P_0 is the saturation pressure, θ is the fractional surface coverage, and C is a constant related to the adsorption energy.

iii. **Freundlich Adsorption Isotherm:** The Freundlich model is an empirical equation that describes non-ideal adsorption behavior, particularly for heterogeneous surfaces. It assumes a logarithmic relationship between the adsorbate concentration and the adsorption capacity. The Freundlich equation is given by:

$$Q = K * C^n$$

where Q is the amount of gas adsorbed, K is the Freundlich constant related to adsorption capacity, C is the gas concentration, and n is an empirical constant related to the adsorption intensity.

These equations provide simplified representations of gas adsorption and can be used to fit experimental data or estimate adsorption parameters. It's important to note that the choice of the appropriate model depends on the specific adsorption system and the assumptions made about the adsorption process.

Advantages of adsorption method in gas

Selectivity: Adsorption is a highly selective process, allowing for the preferential adsorption of specific gases. Different adsorbent materials can be chosen or modified to target and remove specific gases or contaminants from a gas mixture. This selectivity is crucial in gas separation and purification processes, enabling the removal of impurities or the separation of desired gases.

Versatility: Adsorption can be employed for a wide range of gas molecules, including organic compounds, inorganic gases, and even moisture. Various adsorbent materials, such as activated carbon, zeolites, and metal-organic frameworks (MOFs), can be tailored to exhibit specific adsorption properties, making the adsorption method versatile for different gases and applications.

Regenerability: Adsorbent materials can be regenerated and reused, making the adsorption method a cost-effective solution. After adsorption, the adsorbed gases can be desorbed from the adsorbent by applying appropriate conditions such as temperature, pressure, or vacuum. This regeneration process allows for the recovery of the adsorbent material's capacity, reducing the need for frequent replacement.

Large Surface Area: Many adsorbent materials used in gas adsorption have a high surface area, which provides a large number of active sites for gas adsorption. For example, activated carbon can have a surface area of several hundred to thousands of square meters per gram. This high surface area maximizes the adsorption capacity and enhances the efficiency of the adsorption process.

Scalability: The adsorption method can be easily scaled up for industrial applications. Adsorption processes can be designed and optimized for large-scale gas separation, purification, and storage. The availability of various adsorbent materials in different forms, such as pellets, powders, or structured beds, allows for flexible and scalable system designs.

Environmental Friendliness: Adsorption can be an environmentally friendly method for gas treatment. It is a physical process that does not involve the use of chemicals or generate harmful by-products. Activated carbon, a commonly used adsorbent, is derived from renewable sources like coconut shells or wood, making it a sustainable option for gas adsorption applications.

Wide Range of Applications: The adsorption method finds applications in diverse fields, including air and water purification, gas separation, gas storage, and sensing. It is utilized in industries such as petrochemicals, food and beverage, pharmaceuticals, environmental protection, and many others, highlighting its broad range of uses and benefits.

Overall, the adsorption method in gas provides selectivity, versatility, regenerability, and scalability, making it a valuable technique for gas treatment and separation processes in various industries.

Disadvantage of adsorption method for Gas

While the adsorption method for gas offers several advantages, it also has some limitations and disadvantages that should be considered. Here are a few disadvantages of the adsorption method:

Equilibrium and Kinetic Limitations: Adsorption is a dynamic process that reaches equilibrium over time. The rate at which adsorption occurs can be slow, particularly for gases with low concentrations or low affinities for the adsorbent material. This can result in longer contact times or larger adsorbent volumes required for efficient adsorption, making the process less efficient for certain applications.

Adsorbent Capacity and Regeneration: Adsorbent materials have a limited adsorption capacity, which can decrease over time as the adsorbent becomes saturated. Once the adsorbent reaches its maximum capacity, it may need to be replaced or regenerated through energy-intensive processes such as heating or desorption. Regeneration can require additional resources and may result in increased operational costs.

Selectivity Challenges: While adsorption offers selectivity, achieving high selectivity for specific gases can be challenging. Some gases may have similar adsorption properties, making it difficult to selectively remove or separate them. Designing adsorbent materials with high selectivity can be complex and may require significant research and development efforts.

Temperature and Pressure Sensitivity: The adsorption process can be influenced by temperature and pressure conditions. Changes in temperature and pressure can affect the adsorption capacity, efficiency, and selectivity of the adsorbent material. Certain adsorbents may have narrow operating temperature and pressure ranges, limiting their applicability in some environments or processes.

Cost and Availability of Adsorbents: The cost and availability of adsorbent materials can vary depending on the specific type and quality. Some specialized adsorbents, such as certain metal-organic frameworks (MOFs), can be expensive or challenging to produce at a large scale. This can impact the overall cost-effectiveness of the adsorption method, particularly for industrial applications.

Complexity of System Design: Designing an effective adsorption system involves considerations such as mass transfer rates, bed design, and optimization of operating conditions.

The complexity of system design and the need for proper engineering can add to the overall cost and complexity of implementing adsorption-based processes.

Waste Generation: During the regeneration of adsorbents, waste streams containing desorbed or concentrated gases may be generated. Proper management and treatment of these waste streams are required to ensure environmental and safety compliance.

3.3.2. Absorption:

Absorption involves the penetration of gas molecules into the bulk of a liquid or solid material. In this process, the gas molecules are dissolved or incorporated within the absorbing medium. The absorption of gaseous pollutants occurs when the gas molecules interact with a liquid or solid material, resulting in their incorporation into the material's structure. Absorption is commonly employed in various applications, such as gas scrubbers or chemical processes that aim to remove specific gases from gas mixtures. For example, in wet scrubbers, a liquid solvent is used to absorb gaseous pollutants by allowing the pollutants to dissolve into the liquid phase. The liquid acts as an absorbing medium, effectively removing the pollutants from the gas stream. It's important to note that adsorption and absorption are distinct processes, differing in the way gas molecules interact with the adsorbent or absorbing material. Adsorption primarily involves surface attachment, while absorption involves penetration into the bulk of the material. The choice between adsorption and absorption techniques depends on factors such as the nature of the pollutant, the available adsorbents or absorbents, and the desired efficiency of pollutant removal.

Here are a few examples of the absorption method for gas:

a) Gas Purification:

Absorption is frequently employed to remove impurities from gases. For instance, in natural gas processing, acid gases such as carbon dioxide ($\mathrm{CO_2}$) and hydrogen sulfide ($\mathrm{H_2}S$) are removed by passing the gas through an absorber column containing a liquid absorbent, often amine solutions. The acid gases react with the amine, forming stable compounds that are soluble in the liquid phase, while the purified gas exits the column.

b) Gas-Liquid Reactions:

Absorption can be used to facilitate chemical reactions between gases and liquid reactants. For instance, the absorption of carbon dioxide (CO_2) in water is a crucial step in carbon capture and storage (CCS) technologies. The absorbed (CO_2) can be subsequently utilized or stored for reducing greenhouse gas emissions.

c) Gas Separation:

Absorption can be employed to separate specific gases from a gas mixture based on their solubility in a particular absorbent. This is commonly used in processes like solvent-based natural gas sweetening, where certain gases like hydrogen sulfide are selectively absorbed, separating them from the natural gas stream.

d) Air Scrubbing:

Absorption methods can be used for air scrubbing to remove pollutants or odorous compounds. Activated carbon is often used as an absorbent in air filters or scrubbers to trap volatile organic compounds (VOCs) or other airborne contaminants, improving air quality.

The choice of absorbent depends on factors such as the gas composition, desired separation efficiency, and operating conditions. Liquid solvents, solid adsorbents, or reactive absorbents can be utilized depending on the specific requirements of the application. The design and optimization of absorption systems involve considerations such as mass transfer rates, equilibrium solubility, and the overall efficiency of the gas-liquid contact.

Formula of Absorption method for Gas

The absorption method for gas does not have a universal formula, as it can vary depending on the specific system and the absorbent used. However, there are mathematical models and equations that are commonly used to describe aspects of gas absorption processes. Here are a few examples:

Henry's Law: Henry's Law relates the equilibrium concentration of a gas in a liquid to its partial pressure in the gas phase. It is often used to describe the solubility of gases in liquids during absorption processes. The equation is given by:

$$C = k * P$$

where C is the equilibrium concentration of the gas in the liquid, k is the Henry's Law constant, and P is the partial pressure of the gas.

Mass Transfer Coefficient: The mass transfer coefficient (Kg) is a parameter that quantifies the rate of mass transfer between the gas and liquid phases in an absorption system. It represents the efficiency of the gas absorption process. The rate of gas absorption can be expressed using the following equation:

$$N = Kg * (Cg - Cl)$$

where N is the mass transfer rate, Cg is the concentration of the gas in the gas phase, and Cl is the concentration of the gas in the liquid phase

Overall Mass Transfer Coefficient: The overall mass transfer coefficient (Koverall) takes into account both the liquid phase resistance and the gas phase resistance to mass transfer. It can be calculated using the following equation:

$$K_{overall} = 1 / (1/Kg + 1/Kl)$$

where Kl is the mass transfer coefficient in the liquid phase.

These equations provide simplified representations of gas absorption processes and can be used to estimate or predict the behavior of the system. It's important to note that the specific equations and models used can vary depending on the absorption system, the properties of the gas and liquid phases, and other factors specific to the process.

3.4. Particulate matter

Particulate matter (PM) refers to a complex mixture of solid or liquid particles suspended in the air. These particles can vary in size, composition, and origin, and they play a significant role in air pollution and human health effects. Particulate matter is classified based on the size of the particles. Here are the commonly recognized types of particulate matter:

PM10:

PM10 refers to particles with an aerodynamic diameter of 10 micrometers or less. These particles are inhalable and can penetrate into the respiratory system, reaching the upper airways and potentially the lungs. PM10 includes a range of particles, such as dust, pollen, mold spores, larger combustion particles, and some coarse particles from industrial activities and construction sites.

PM2.5:

PM2.5 refers to particles with an aerodynamic diameter of 2.5 micrometers or less. These particles are smaller than PM10 and can penetrate deeper into the respiratory system, reaching the lower airways and even the bloodstream. PM2.5 is a major concern for air quality and health effects because of its ability to bypass the body's natural defense mechanisms. It includes combustion particles, fine dust, vehicle emissions, secondary aerosols, and various chemical constituents.

PM1:

PM1 refers to particles with an aerodynamic diameter of 1 micrometer or less. These particles are even smaller and have a higher likelihood of being deposited deep within the respiratory system. PM1 is composed of fine combustion particles, secondary aerosols, organic compounds, metals, and other pollutants. It is often associated with urban areas, traffic emissions, and industrial processes.

Ultrafine Particles (UFP):

Ultrafine particles, also known as nanoparticles, have a diameter of less than 0.1 micrometers. UFPs are extremely small and highly mobile in the air. Due to their small size, they can penetrate deep into the lungs and may even translocate into the bloodstream. UFPs primarily originate from combustion processes, including vehicle exhaust, power plants, and industrial emissions. They can contain various toxic components and pose potential health risks.

It's important to note that particulate matter can vary in composition depending on the emission sources, geographical location, and atmospheric conditions. The composition of PM can include elements, organic compounds, metals, sulfates, nitrates, black carbon, and other substances. The size and chemical composition of particulate matter play a crucial role in determining its effects on human health and the environment. Regulatory agencies and health organizations monitor and set standards for particulate matter concentrations to protect public health and manage air quality.

Source of particulate matter:

Particulate matter (PM) can originate from a variety of natural and anthropogenic sources. Here are some common sources of particulate matter:

- **Industrial Emissions**: Combustion of fossil fuels in industries, power plants, and manufacturing processes releases particulate matter. This includes emissions from boilers, furnaces, and other combustion equipment.
- **Vehicle Exhaust**: The combustion of gasoline and diesel fuels in vehicles produces particulate matter, especially from diesel engines. Exhaust emissions contain fine particles, black carbon, and other pollutants.
- **Residential Heating and Cooking**: Particulate matter can arise from the burning of wood, coal, and other solid fuels for residential heating and cooking, particularly in households without proper ventilation or inefficient combustion practices.
- **Industrial Processes**: Mining and Quarrying: Activities involving mining, excavation, and quarrying can generate dust particles, contributing to particulate matter in the nearby areas.
- **Construction and Demolition**: Construction activities produce dust from activities such as excavation, demolition, material handling, and land clearing, which can contribute to particulate matter.
- **Agricultural Activities**: Crop Residue Burning: The burning of agricultural residues, such as crop stubble or biomass, after harvest can release significant amounts of particulate matter into the atmosphere, especially in agricultural regions.
- **Livestock Farming:** Animal agriculture, including intensive livestock farming, can release particulate matter from animal waste, feed handling, and barn emissions.
- **Natural Sources:** Windblown Dust: Particulate matter can arise from the suspension of dust particles by wind, especially in arid or semi-arid regions, construction sites, and unpaved roads.
- **Volcanic Eruptions:** Volcanic activity can release ash and other particulate matter into the atmosphere during eruptions.
- **Sea Spray:** Breaking waves and oceanic processes release sea salt particles, which can contribute to particulate matter in coastal regions.
- **Biological Sources**: Pollen and Biological Particles: Pollen grains, spores, and other biological particles from plants, trees, and fungi can contribute to particulate matter, particularly during the pollen season or in areas with high vegetation density.

- **Secondary Formation**: Chemical Reactions: Gaseous pollutants, such as sulfur dioxide (SO_2)) and nitrogen oxides (NO_x), can undergo chemical reactions in the atmosphere to form secondary particulate matter. These reactions can lead to the formation of sulfates, nitrates, and other particulate compounds.

It's important to note that the contribution of different sources to particulate matter can vary depending on geographical location, local emission sources, and meteorological conditions. Effective management strategies targeting specific sources are crucial for reducing particulate matter pollution and protecting human health and the environment.

Characteristics of particulate matter:

Particulate matter (PM) exhibits several characteristics that influence its behavior, sources, and impacts. Here are some key characteristics of particulate matter:

- **Size Distribution**: Particulate matter encompasses a range of particle sizes, from large visible particles to ultrafine particles. PM is often categorized based on size fractions, such as PM10, PM2.5, and PM1. The size distribution of particles affects their transport, inhalation, and deposition patterns in the atmosphere and human respiratory system.
- **Composition:** Particulate matter can have diverse chemical compositions depending on its sources and atmospheric processes. It may contain organic compounds, metals, sulfates, nitrates, ammonium, black carbon, mineral dust, and other substances. The composition of PM plays a crucial role in its toxicity, reactivity, and environmental impacts.
- **Source Apportionment:** Different sources contribute to the formation of particulate matter. These sources include combustion processes (such as vehicle emissions, industrial operations, and biomass burning), dust and soil erosion, natural sources (such as sea spray and volcanic emissions), and secondary formation from precursor gases. Identifying the sources of particulate matter is important for effective mitigation strategies and regulatory actions. Morphology: Particulate matter can have various shapes and structures. It can range from spherical particles to irregular shapes, fibers, agglomerates, or fractal-like structures. The morphology of PM influences its aerodynamic properties, deposition patterns, and interactions with atmospheric processes.
- **Hygroscopicity:** Many particles have the ability to absorb water vapor from the surrounding air, altering their size and properties. Hygroscopic particles can influence cloud formation,

precipitation, and atmospheric visibility. The hygroscopic behavior of particulate matter depends on its composition and relative humidity.

- **Residence Time:** The residence time of particulate matter refers to the duration that particles remain in the atmosphere before being removed through deposition processes (such as dry deposition or wet deposition through precipitation). Fine particles (PM2.5 and smaller) can have longer residence times, allowing them to disperse over larger distances and potentially affecting regional and even global air quality.
- **Health Impacts:** The characteristics of particulate matter, including its size, composition, and surface properties, determine its potential health effects. Fine particles (PM2.5) and ultrafine particles (UFPs) can penetrate deep into the respiratory system and have higher toxicological implications than larger particles. The chemical constituents, such as metals or organic compounds, present in PM also contribute to its health impacts.

Understanding the characteristics of particulate matter is essential for assessing its sources, transport, behavior in the atmosphere, and associated health and environmental impacts. These characteristics guide regulatory measures, air quality management strategies, and research efforts aimed at mitigating the adverse effects of particulate matter pollution.

Significance of particulate matter:

Particulate matter (PM) has significant implications for human health, the environment, and climate. Exposure to particulate matter, especially fine particles (PM2.5 and PM1), has been linked to a wide range of adverse health effects. When inhaled, these particles can penetrate deep into the respiratory system, leading to respiratory and cardiovascular problems. Particulate matter has been associated with increased risks of asthma, bronchitis, reduced lung function, heart attacks, strokes, and premature death. The smaller particles (UFPs) can potentially translocate into the bloodstream and affect various organs, including the heart and brain.

Particulate matter contributes to degraded air quality. It reduces visibility and creates haze, particularly in urban and industrial areas. High levels of particulate matter can also lead to the formation of smog, adversely affecting air quality and the overall environmental aesthetics. Particles can also deposit onto surfaces, including buildings, plants, and water bodies, causing aesthetic damage, soiling, and potentially impacting ecosystems.

Particulate matter influences the Earth's climate by scattering and absorbing sunlight. Certain particles, such as black carbon or soot, absorb solar radiation, leading to localized heating and potentially contributing to global warming. Other particles, like sulfates and nitrates, can act as aerosols and reflect sunlight, thereby cooling the atmosphere. These interactions affect regional and global temperature patterns and influence climate change dynamics.

Particulate matter can carry various toxic substances, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), and other hazardous air pollutants. These toxic components can adhere to the surface of particles and be transported over long distances. When inhaled or ingested, these substances can pose significant health risks, including cancer, neurological effects, and reproductive issues.

Due to the health and environmental impacts of particulate matter, regulatory agencies worldwide have established standards and guidelines to limit particulate matter concentrations in ambient air. These regulations aim to protect public health, improve air quality, and minimize the associated risks. Compliance with these standards is essential for industries, transportation, and other sectors to mitigate the emissions of particulate matter.

Understanding the significance of particulate matter helps drive efforts toward pollution control, adopting cleaner technologies, implementing effective air quality management strategies, and promoting sustainable practices. It highlights the need for monitoring and reducing particulate matter emissions to safeguard human health, protect the environment, and mitigate climate change impacts.

3.5. Collection equipment for air sample

There are various collection equipment and techniques available for air sampling to capture particulate matter and other pollutants. The selection of the appropriate equipment depends on the specific pollutants of interest, the sampling objectives, and the analytical methods used for subsequent analysis. Few examples of air sampling equipment and techniques available for different types of pollutants are mentioned here:

Collection equipment for air sample

a. High Volume Sampler:

High volume samplers draw large volumes of air through filters, typically at flow rates ranging from 40 to 60 cubic feet per minute (cfm). These samplers are commonly used for the collection of total suspended particulates (TSP) or specific size fractions such as PM10. They employ filters to capture the particulate matter for subsequent analysis. Low Volume Sampler: Example: Andersen High-Volume Sampler, PM10 High-Volume Sampler

Fig.3.1: High volume samplers

b. Low Volume Sampler:

Low volume samplers are portable and often worn by individuals to measure personal exposure to particulate matter and other contaminants. They typically operate at lower flow rates (e.g., 2 to 5 liters per minute) and collect samples on filters or sorbent media. Example: Personal Air Sampler (e.g., SKC AirChek XR5000)

Fig.3.2: Low Volume sampler

c. Impactors:

Impactors are used to separate particles based on their aerodynamic size. They work by directing the air sample through a series of stages or plates with small holes, causing particles of different sizes to deposit on each stage. This allows for the collection of particles in different size ranges for subsequent analysis. Example: Andersen Cascade Impactor.

Fig.3.3: Impactors

d. **Cyclone Separator**:

Cyclone separators utilize centrifugal force to separate particles based on their size. The air sample is introduced tangentially into the cyclone, causing larger particles to be forced toward the walls and collected, while smaller particles continue in the airflow. Cyclone separators are commonly used for collecting respirable fractions of particulate matter. Example: Sharp Cut Cyclone

e. **Filtration Systems**:

Filters are widely used in air sampling to capture particulate matter. Different types of filters, such as quartz fiber filters or Teflon filters, can be selected based on the nature of the particles and subsequent analysis requirements. Filters collect particles by physically trapping them as the air passes through. Example: Quartz Fiber Filters, Teflon Filters

f. **Sorbent Tubes:**

Sorbent tubes are used to capture gaseous pollutants and volatile organic compounds (VOCs) present in the air. The tubes contain adsorbent materials, such as activated charcoal or Tenax, which adsorb the gases for later analysis.

g. **Real-time Monitoring Instruments:**

Real-time monitoring instruments provide immediate measurements of particulate matter concentrations without the need for sample collection. Optical particle counters (OPCs) use light scattering techniques to measure particle size and count, while instruments like DustTrak Monitors combine real-time measurements with size-selective sampling. Example: Optical Particle Counters (OPCs), DustTrak Monitors

In addition, the brief description of some other particulate matter collectionsequipmentsarementioned here such as

3.6. Settling chamber

A settling chamber is a type of air sampling device used to collect and analyze particulate matter. It is a simple and passive method that relies on the gravitational settling of particles to separate them from the air stream. A settling chamber consists of a large, open chamber or box-like structure with an inlet and an outlet for the airflow. The chamber is designed to allow the air to slow down as it enters, allowing the larger and heavier particles to settle out under the force of gravity. The settled particles are then collected at the bottom of the chamber for subsequent analysis. Settling chambers are commonly used in various settings, including indoor air quality assessments, industrial hygiene monitoring, and research studies. They can provide valuable information on the concentration and composition of larger-sized particles in the sampled air.

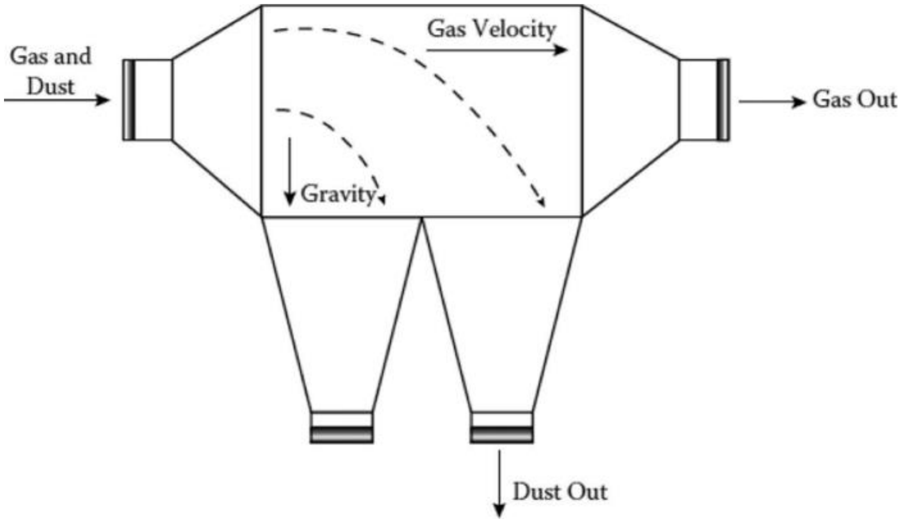

Fig.3.4: Settling chamber

Working Principle:

When the air carrying particulate matter enters the settling chamber, its velocity decreases, causing a reduction in the air's kinetic energy. As a result, the larger and heavier particles suspended in the air lose their momentum and settle due to gravitational forces. The settled particles fall down to the bottom of the chamber due to their weight, while the cleaned air exits through the outlet.

Advantages:

iv. Settling chambers are relatively simple in design and operation, requiring minimal maintenance and power input.
v. Compared to other air sampling methods, settling chambers are often less expensive to set up and operate.
vi. Settling chambers can collect a substantial volume of particles due to their larger size and capacity, enabling a representative sample to be obtained.

Limitations:

1. Settling chambers are more effective at capturing larger particles, while smaller particles may remain suspended in the air and bypass the settling process.
2. Settling chambers require a sufficient residence time for particles to settle out, which means longer sampling durations may be necessary to capture a representative sample.
3. Settling chambers are best suited for relatively large particles and are less effective for collecting fine particulate matter, which may require other sampling methods such as impactors or filters.

1.7.Cyclones

Cyclones are commonly used air sampling devices that separate particulate matter based on their size through the principle of centrifugal force. Cyclones are designed to collect respirable fractions of particulate matter and are widely employed in various industrial and environmental applications. A cyclone consists of a cylindrical body with an inlet nozzle, a conical section, and an outlet. The air sample enters tangentially through the inlet, creating a swirling vortex inside the cyclone. As the air moves through the cyclone, particles with sufficient mass and inertia are forced toward the walls and eventually deposit onto the walls or collection surfaces. The cleaned air exits through the outlet.

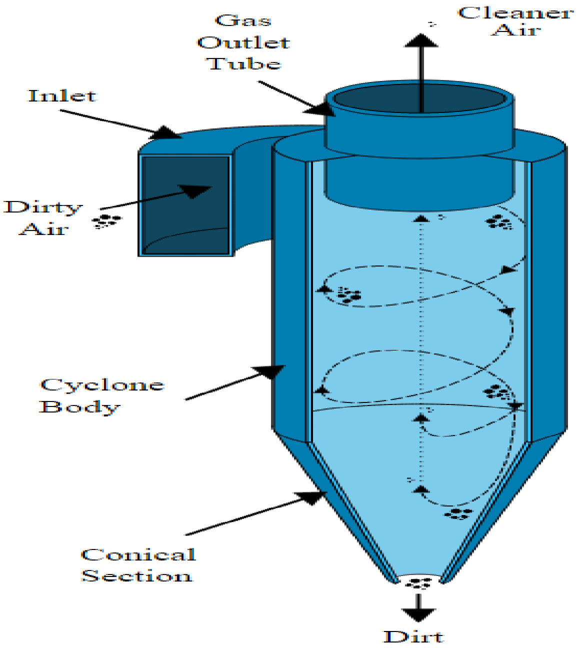

Fig.3.4: Cyclones

Working Principle:

Cyclones operate based on the principle of centrifugal force. As the air stream enters the cyclone tangentially, it acquires angular momentum and starts rotating inside the cyclone. Due to the centrifugal force generated by the swirling motion, particles with larger masses and sizes tend to move toward the walls, while smaller particles continue in the airflow and exit through the outlet. The size of particles that can be collected by a cyclone depends on the design parameters, such as the dimensions of the cyclone body, the angle of the conical section, and the airflow rate. Cyclones are typically designed to collect respirable particles in the range of 1 to 10 micrometers, making them suitable for sampling inhalable fractions of particulate matter. Cyclones are widely used in occupational health monitoring, indoor air quality assessments, ambient air pollution studies, and research applications. They are commonly employed to sample respirable fractions, such as PM2.5 and PM10, and are integrated with subsequent analysis techniques, such as gravimetric analysis or chemical analysis for specific pollutants.Here are some types of cyclone equipment commonly used for gas collection:

1. **Reverse-Flow Cyclone Separator:** This type of cyclone separator is designed with a tangential inlet at the bottom and an axial outlet at the top. The gas enters the cyclone tangentially, creating a swirling motion that forces the particles towards the wall. The

separated particles then move downward due to gravity and are collected at the bottom of the cyclone. Reverse-flow cyclone separators are widely used for gas-solid separation in industries such as cement, mining, and power generation.

2. **Multi-Cyclone Separator:** Multi-cyclone separators consist of multiple cyclone units arranged in parallel or series. The gas stream is divided among the cyclone units, allowing for enhanced particle separation efficiency. Multi-cyclone separators are often used in applications where a high level of particle removal is required, such as air pollution control systems and industrial dust collectors.
3. **Axial Flow Cyclone Separator:** Axial flow cyclone separators have an axial inlet and an axial outlet. The gas stream enters the cyclone along the axis, creating a spinning motion. The centrifugal force causes the particles to move towards the outer wall, where they are collected. Axial flow cyclones are suitable for gas-solid separation in applications with high gas flow rates and relatively small particle sizes.
4. **Gas-Liquid Cyclone Separator:** Gas-liquid cyclone separators are designed to separate liquid droplets from a gas stream. They use the same principles as particle separation cyclones, but with modifications to accommodate the presence of liquid droplets. Gas-liquid cyclones are commonly used in applications such as natural gas processing, oil refineries, and wastewater treatment.
5. **High-Efficiency Cyclone Separator:** High-efficiency cyclone separators are designed to achieve a higher particle separation efficiency compared to standard cyclones. They often incorporate additional features, such as a long vortex finder, an extended barrel section, or internal vanes, to improve particle collection and reduce particle re-entrainment. High-efficiency cyclones are used in applications where strict emission standards or fine particle collection is required, such as in certain industrial processes and air pollution control systems.

Advantages:

1. Cyclones are designed to efficiently collect respirable fractions of particulate matter, which are of particular interest for assessing human exposure and health effects.
2. Cyclones do not require external power or pumps, making them relatively simple and cost-effective to use.

3. Cyclones have low pressure drops and minimal particle losses, allowing for accurate representation of the particle size distribution.

Limitations:

i. Cyclones have a specific cut-off size, above which particles are effectively collected, while smaller particles may bypass the cyclone and remain suspended in the air.
ii. Cyclone performance can be affected by variations in airflow rate, temperature, humidity, and particle density. Calibration and optimization are necessary for accurate sampling.
iii. Cyclones may exhibit reduced efficiency for collecting non-spherical or irregularly shaped particles compared to spherical particles.

1.8.Filters

Filters are widely used in air sample analysis to collect and retain particulate matter for subsequent laboratory analysis. Filters provide a means to capture and concentrate airborne particles, allowing for various characterization and quantification techniques. The selection of the appropriate filter depends on factors such as the nature of the particulate matter, the desired analytical techniques, and any specific requirements of the regulatory standards or research objectives. It's important to consider the compatibility of the filter material with the intended analysis and ensure that the selected filter does not introduce artifacts or interfere with the subsequent analysis methods.

Fig.3.5: Quartz fiber filters

Examples of filter used in gaseous pollution collection are such as:

i. **Quartz fiber filters:**

Quartz fiber filters are made of high-purity quartz fibers, which offer excellent chemical resistance and low background contamination. Quartz fiber filters are commonly used for the collection of particulate matter in both indoor and outdoor air monitoring. They are suitable for gravimetric analysis, elemental analysis, and organic compound analysis.

ii. **Teflon (PTFE) Filters:** Teflon (polytetrafluoroethylene or PTFE) filters are chemically inert and have high-temperature resistance. Teflon filters are used for sampling and analysis of airborne particulates, especially for collecting particles that may react or adsorb onto other filter materials. They are suitable for various chemical and biological analyses.

iii. **Glass Fiber Filters:**

Glass fiber filters are made from fine glass fibers and are available in different pore sizes. Glass fiber filters are commonly used for the collection of both particulate matter and aerosols. They are suitable for gravimetric analysis, microscopic examination, and other analytical techniques.

iv. **Membrane Filters:**

Membrane filters are thin, microporous membranes made of materials such as cellulose nitrate, cellulose acetate, or mixed esters. Membrane filters are used for collecting particulate matter and microorganisms in air samples. They are commonly used in microbiological analysis and microbial air quality assessments.

v. **PTFE Membrane Filters:**

PTFE membrane filters are hydrophobic and chemically inert. PTFE membrane filters are suitable for the collection of particulate matter and aerosols in air samples, especially for samples with high moisture content or chemical reactivity. They are often used in the analysis of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs).

vi. **Polycarbonate Filters:**

Polycarbonate filters are made of a durable and transparent material. Polycarbonate filters are used for the collection of airborne particles in various air quality monitoring applications. They are particularly useful for microscopy and particle size distribution analysis.

1.9. Electrostatic precipitation

Electrostatic precipitation is a technique used for air sample analysis that involves the use of an electrostatic precipitator (ESP). An ESP uses electric fields to remove particulate matter from an air stream. An electrostatic precipitator consists of a series of plates or tubes arranged parallel to the airflow. The plates are charged with a high voltage, creating an electrostatic field within the device. As the air passes through the ESP, the particles become charged by ionization or corona discharge. The charged particles are then attracted to the oppositely charged plates and collect on them. The cleaned air continues its flow, while the particles are retained on the collection surfaces. Electrostatic precipitation is used in various applications, including industrial emissions control, indoor air quality monitoring, and research studies. It is particularly suitable for collecting and analyzing fine particulate matter, such as PM2.5 or PM1, as well as ultrafine particles. ESPs are commonly employed in air pollution control systems and can be integrated with subsequent analysis techniques, such as gravimetric analysis, chemical analysis, or particle characterization methods.

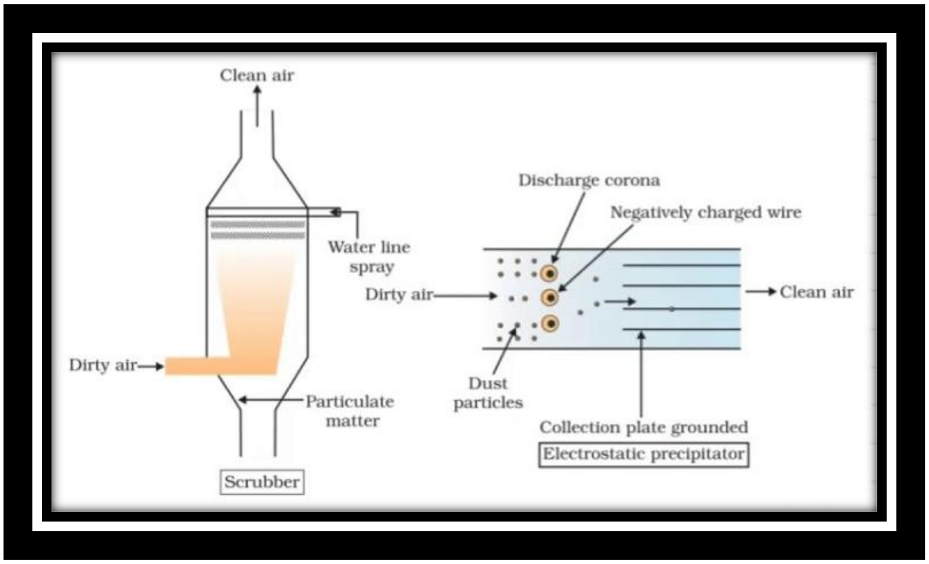

Fig. 3.6: electrostatic precipitator

Working Principle:

The principle of electrostatic precipitation is based on the attraction of charged particles to oppositely charged surfaces. When an electric field is applied, the particles in the air become charged by gaining or losing electrons. The charged particles are then influenced by the electric field and migrate towards the collection surfaces, where they adhere and accumulate. The collection surfaces can be cleaned periodically to remove the accumulated particulate matter.Here are some common types:

a) Plate-Type Electrostatic Precipitator:

This type of ESP consists of a series of parallel plates arranged in the gas flow path. The plates are charged with high voltage, creating an electric field. As the gas passes through the plates, the charged particles are attracted to the plates and collect on them. Plate-type ESPs are suitable for high-efficiency particle collection and are often used in industries such as power generation, cement manufacturing, and steel production.

b) Tubular Electrostatic Precipitator:

Tubular ESPs consist of a series of tubular electrodes arranged in a cylindrical configuration. The gas stream passes through the center of the tubes, while the outer surface of the tubes is charged. The charged particles in the gas stream are attracted to the tubular electrodes and adhere to them. Tubular ESPs are commonly used in applications where space is limited, such as small-scale industrial processes and laboratory settings.

c) Wet Electrostatic Precipitator:

Wet ESPs utilize water or another liquid as a medium to enhance the particle collection efficiency. The liquid is sprayed into the gas stream, creating a mist or fog that increases the chances of particle capture. The charged particles combine with the liquid droplets and are collected as a wet sludge. Wet ESPs are particularly effective in removing fine particles and certain types of aerosols. They are commonly used in applications such as air pollution control in waste incineration plants and industrial boilers.

d) Dry Electrostatic Precipitator:

Dry ESPs operate without the use of liquid as a collection medium. The gas stream passes through a charged electrode system, and the particles are attracted to the charged surfaces. The collected particles are then periodically removed through rapping or vibration mechanisms. Dry ESPs are widely used in various industries, including power plants, cement kilns, pulp and paper mills, and chemical processes.

e) Two-Stage Electrostatic Precipitator.

Two-stage ESPs consist of two distinct ESP sections designed to remove particles of different sizes. The first stage focuses on larger particles, while the second stage targets finer particles. Two-stage ESPs offer higher collection efficiencies and are suitable for applications where a wide range of particle sizes need to be controlled, such as in biomass combustion or waste-to-energy plants.

Advantages:

Electrostatic precipitators can achieve high collection efficiencies, typically ranging from 90% to 99%, depending on the particle size and properties.ESPs are effective in capturing a wide range of particle sizes, including both fine and coarse particles. Continuous Operation: Electrostatic precipitators can operate continuously, making them suitable for continuous air monitoring and sample collection.ESPs have relatively low pressure drops, resulting in minimal energy consumption and allowing for the analysis of large air volumes.

Limitations:

The efficiency of electrostatic precipitation may be reduced for particles with high electrical resistivity, as they tend to hold their charges and are less responsive to the electric field.In some cases, electrostatic precipitators can generate ozone as a byproduct of the ionization process, which may be a concern in certain environments or for sensitive applications.Periodic cleaning of the collection surfaces is necessary to prevent excessive particle buildup and ensure continued efficiency.

1.10. Scrubberand wet collectors

Scrubbers and wet collectors are air pollution control devices used to remove pollutants, including gases and particulate matter, from industrial exhaust gases or air streams. They operate by utilizing liquid solutions or slurries to capture and remove the contaminants.

1.10.1. Scrubbers

Scrubbers are devices that use liquid solutions or reagents to chemically react with and remove pollutants from the gas stream. The contaminated gas is passed through the scrubber, where the liquid contacts the pollutants, leading to their absorption, chemical reaction, or physical capture. The cleaned gas is then released into the atmosphere. Scrubbers are versatile air pollution control devices commonly used in industrial settings to reduce emissions and ensure compliance with environmental regulations. The specific type of device chosen depends on the pollutants to be controlled, the process conditions, and the desired removal efficiency.

There are different types of scrubbers, including:

i. **Wet Scrubbers:** Wet scrubbers use liquid solutions or suspensions to capture pollutants through absorption, impaction, or reaction. Wet scrubbers are effective for removing gases, aerosols, and particulate matter. They are commonly used in industries such as power plants, chemical plants, and metal processing facilities.

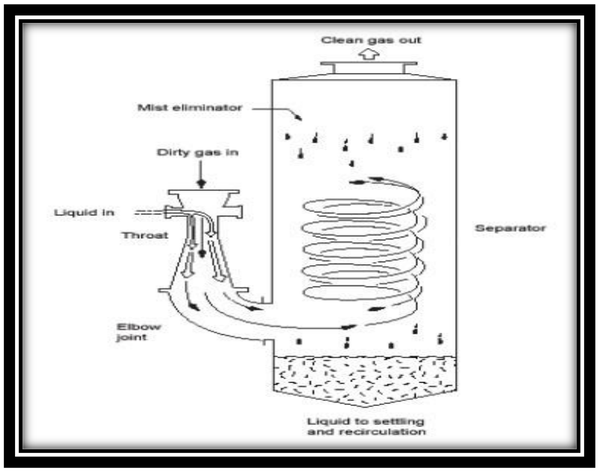

Fig.3.7: Wet scrubbers

ii. **Venturi Scrubbers:** Venturi scrubbers use the principle of gas acceleration and liquid atomization to capture and remove pollutants. Venturi scrubbers are suitable for removing fine particles and aerosols. They are often used in applications with high gas velocities, such as incinerators and certain industrial processes.

iii. **Packed Bed Scrubbers**: Packed bed scrubbers consist of a tower filled with packing material that enhances contact between the gas and liquid phases. Packed bed scrubbers are effective for removing soluble gases and some particulate matter. They are used in various industries, including chemical manufacturing and wastewater treatment.

1.10.2. Wet Collectors:

Wet collectors, also known as wet dust collectors or wet cyclones, are devices that use liquid sprays or immersion to capture and collect particulate matter. These collectors utilize the principle of impaction and adhesion to remove the particles from the gas stream. Wet collectors are commonly used in applications where dry collection methods are not effective or where wet scrubbing is not required. Some examples include:

i. **Wet Cyclones:** Wet cyclones combine the principles of cyclone separators with the addition of liquid sprays to enhance particle collection efficiency. Wet cyclones are effective for removing larger-sized particulate matter, such as in mining and mineral processing operations.
ii. **Wet Electrostatic Precipitators (WESPs):** WESPs are electrostatic precipitators that use water or a liquid solution to enhance particle capture efficiency. WESPs are suitable for removing fine particles and aerosols, and they are often used in applications such as metal finishing, glass manufacturing, and biomass combustion.

Advantages of Scrubbers and Wet Collectors:

a. Effective for capturing both gases and particulate matter.
b. Can remove soluble and reactive pollutants through chemical reactions.
c. Can handle high gas temperatures and corrosive gases
d. Provide a high removal efficiency for fine particle

Limitations of Scrubbers and Wet Collectors:

i. Consumes water and requires water treatment or wastewater management.
ii. Maintenance and cleaning are required due to liquid handling.
iii. Can be bulky and require significant installation space.
iv. Operating costs associated with liquid consumption and disposal.

1.11. Control of particulate matter

The control of particulate matter (PM) in the air is crucial for maintaining good air quality and protecting human health. Several techniques and strategies are employed to control and reduce the emission and dispersion of particulate matter. Here are some common methods for particulate matter control:

Source Control:

- Implementing cleaner production technologies and practices to minimize the generation of particulate matter at its source.
- Using alternative raw materials with lower particulate matter emissions.
- Optimizing industrial processes and equipment to reduce particle formation and emissions.
- Implementing proper maintenance and operation practices to prevent fugitive dust emissions.

Filtration and Separation:

Using air filters and particulate control devices such as cyclones, electrostatic precipitators, fabric filters (baghouses), and scrubbers to capture and remove particulate matter from industrial exhausts and emission sources. Choosing the appropriate filter media and design parameters based on the particle size, characteristics, and operating conditions.

Dust Suppression: Applying water or dust suppressants to minimize the generation and dispersion of dust from construction sites, unpaved roads, and other dusty operations.Using enclosures, barriers, or covers to confine particulate matter sources and prevent their dispersion.

Emission Standards and Regulations: Implementing and enforcing emission standards and regulations that limit particulate matter emissions from industrial processes, power plants, vehicles, and other pollution sources.Regular monitoring and reporting of particulate matter emissions to ensure compliance with the established standards.

Alternative Energy Sources: Shifting to cleaner and renewable energy sources, such as solar, wind, and hydroelectric power, which have lower or no particulate matter emissions compared to fossil fuel combustion. Promoting energy efficiency and conservation to reduce the overall energy demand and associated particulate matter emissions.

Public Awareness and Education:Raising awareness among the public, industries, and policymakers about the health and environmental impacts of particulate matter pollution. Encouraging responsible practices, such as proper waste management, reducing open burning, and promoting sustainable transportation options.

Urban Planning and Land Use Management: Designing and implementing land use plans that minimize the proximity of sensitive receptors (e.g., residential areas, schools, hospitals) to major sources of particulate matter emissions. Promoting green spaces and vegetation in urban areas, which can help mitigate particulate matter by acting as natural filters and reducing dust generation. A comprehensive approach that combines multiple strategies is often necessary to achieve significant and sustained reductions in particulate matter pollution. Additionally, continuous monitoring and assessment of air quality are essential to identify areas of concern and evaluate the effectiveness of implemented control measures.

1.12. Impact of particulate matter

Impact on environment

i. Particulate matter contributes to the deterioration of air quality by reducing visibility and creating haze or smog.

ii. Certain types of particulate matter, such as black carbon (soot), absorb solar radiation and contribute to global warming and climate change.

iii. Particulate matter can deposit onto the surfaces of plants, soils, and water bodies, leading to soil acidification, nutrient imbalances, and contamination of aquatic ecosystems.

iv. Particulate matter can negatively affect ecosystems by impairing photosynthesis in plants, reducing crop yields, and harming sensitive organisms such as lichens, mosses, and aquatic organisms.

Impact on Human Health

i. **Respiratory Problems**: Inhalation of particulate matter can cause or exacerbate respiratory conditions such as asthma, bronchitis, and other respiratory tract infections. Fine particles (PM2.5) can penetrate deep into the lungs, leading to inflammation and long-term health issues.

ii. **Cardiovascular Effects**: Particulate matter has been linked to an increased risk of cardiovascular diseases, including heart attacks, strokes, and hypertension. It can enter the bloodstream, triggering inflammation, oxidative stress, and clotting responses.

iii. **Premature Mortality:** Exposure to high levels of particulate matter is associated with increased mortality rates, particularly from respiratory and cardiovascular diseases. Long-term exposure to elevated PM levels can shorten life expectancy.

iv. **Cancer Risk:** Certain toxic components of particulate matter, such as heavy metals and polycyclic aromatic hydrocarbons (PAHs), have carcinogenic properties and can increase the risk of lung cancer and other types of cancer.

v. **Impaired Lung Development:** Children exposed to high levels of particulate matter may experience impaired lung development, leading to reduced lung function and increased susceptibility to respiratory problems later in life.

vi. **Allergenic and Irritant Effects:** Particulate matter can act as carriers for allergens, exacerbating allergic reactions and asthma symptoms. Additionally, some particles have irritant properties, causing eye and throat irritation.

1.13. Summary

Air sampling is a critical process used to collect and analyze air samples to assess air quality, identify pollutants, and understand their sources and impacts. Particulate matter refers to tiny solid or liquid particles suspended in the air. It can be categorized based on its size, with PM10 referring to particles with a diameter of 10 micrometers or less, and PM2.5 referring to particles with a diameter of 2.5 micrometers or less. PM2.5 is of particular concern due to its ability to penetrate deep into the respiratory system and cause adverse health effects. Fine particles (PM2.5) are especially concerning as they can penetrate deep into the lungs, causing inflammation and long-term health issues. PM exposure is also associated with cardiovascular effects, such as an increased risk of heart attacks, strokes, and hypertension. Long-term exposure to elevated PM levels can result in premature mortality, particularly from respiratory and cardiovascular diseases. Settling chambers, cyclones, filters, and electrostatic precipitators are commonly used to capture and collect PM from air samples. Settling chambers allow particles to settle out under the force of gravity, while cyclones utilize centrifugal force to separate particles based on their size and density. Filters, such as high-efficiency particulate air (HEPA) filters, physically capture particles as air passes through them. Electrostatic precipitators use electric fields to attract and collect charged particles. Air sampling and the analysis of particulate matter are essential for assessing air quality, understanding the sources and impacts of PM, and developing strategies to mitigate pollution. Particulate matter has significant environmental consequences, including air pollution, climate change, and ecosystem disruption. It poses serious health risks, including respiratory and cardiovascular problems, premature mortality, and increased cancer risk.

3.14. Terminal questions

Q.1. What are gaseous pollutants? Discuss the sampling of gases pollutants.

Answer: ---

Q.2. What do you know about adsorption and absorption methods? How it is used for gaseous pollutant samplings.

Answer: --

Q.3. What is the particulate matter? Write the types of particulate matter and its sources and characteristics.

Answer: --

Q.4. Discuss the types of gaseous collection equipment. Its advantage and limitations.

Answer: --

Q.5. Briefly discus about settling chamber, its working methods, advantage and limitations.

Answer: --

Q.6. Briefly discus the electrostatic, it’s working methods, advantage and limitations.

Answer: --

3.15. Further suggested readings

1. Environmental Science, Subhas Chandra Santra, new central book agency, 3rd Edition, 2011.
2. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.
3. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd.
4. Textbook of Environmental Chemistry and Pollution Control, S.S.Dara and D.D. Mishra, S. Chand & Co. Ltd.

PGEVS-102N

Rajarshi Tandon Open
University, Prayagraj

Environmental Chemistry

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Block-2

PGEVS-102N

Environmental Chemistry

Rajarshi Tandon Open University, Prayagraj

Block- 2

Water Chemistry and Pollution

UNIT -4
Properties of Water

UNIT-5
Water pollution

UNIT-6
Wastewater and Industrial Effluents

Introduction

This second block of environmental chemistry consists of following three units:

Unit-4: This unit covers the water properties such as structure, formula and chemical composition. The chemical and physical properties of river, lake, and ocean water also discussed.

Unit-5: In this unit covers the source, sink and types of water pollutants. The water quality parameters such as dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved organic carbon (DOC), and total dissolve solid (TDS) and total suspended solid are briefly disused.

Unit-6: This unit covers the meaning of wastewater, industrial effluent, and composition of industrial effluents, sludge and activated sludge. The role of soaps, detergents and phosphorus fertilizers in Eutrophication also discussed. Application of advanced oxidation processes is wastewater mentioned here in briefly.

Unit-4: Properties of Water

Contents

4.1. Introduction

Water plays a vital role in the metabolic process, growth and development of living body. Apart from that water is considered as universal solvent due to polar in nature, water make easily solubility to other substances. Water has several physical and chemical properties that make it suitable to living organism. pH is also referred to hydrogen ion concentration, pH, which is physical parameter, plays important role in mentioning the nature of water that make it solubility. Water formed weak bonds with number of polar and non polar molecules. A buffer is a solution that resists a change in pH on addition of a small amount of acid $[\mathrm{H}^{\mp}]$ or base $[\mathrm{OH}^{-}]$more effectively than an equal volume. Generally, buffer is an aqueous solution consisting of mixture of weak acid and it conjugated base vice versa.

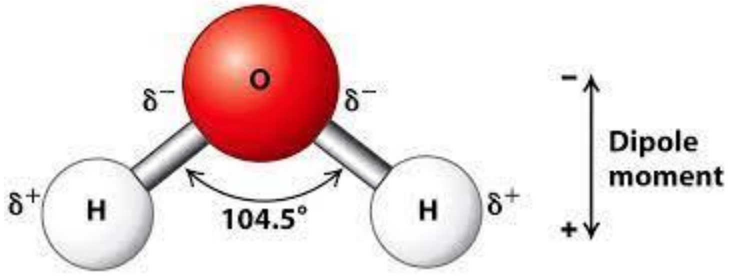
Objectives:

- To understand physical and biological properties of water

- to learn about bonding and chemical nature of water
- to know buffer and pH role in biological reactions

4.2. Structure of water molecule

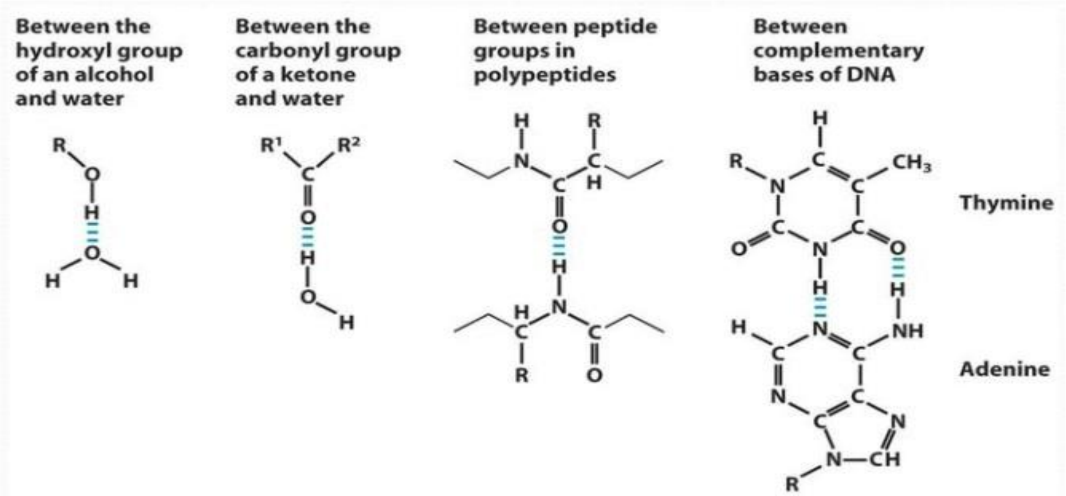
Water molecules have a unique structure due to their composition and the arrangement of their atoms. A water molecule consists of two hydrogen atoms bonded covalently to a central oxygen atom. The chemical formula for water isH_2O, indicating that there are two hydrogen atoms and one oxygen atom in each molecule. A water molecule consists of two hydrogen atoms bonded to an oxygen atom, and its overall structure is bent. This is because the oxygen atom, in addition to forming bonds with the hydrogen atoms, also carries two pairs of unshared electrons. All of the electron pairs-shared and unshared-repel each other. The oxygen atom in water has eight protons in its nucleus, giving it an atomic number of 8. It also has six electrons in its outermost energy level, known as the valence shell. The hydrogen atoms, on the other hand, have one proton each and one electron in their valence shell. The oxygen atom forms covalent bonds with the two hydrogen atoms by sharing electrons. Each hydrogen atom shares one of its electrons with the oxygen atom, while the oxygen atom shares one of its electrons with each hydrogen atom. This sharing of electrons allows each atom to satisfy the octet rule, which states that atoms tend to gain, lose, or share electrons to achieve a stable configuration with eight electrons in their outermost shell. The arrangement of atoms in a water molecule is often described as bent or V-shaped. The oxygen atom is positioned at the center of the molecule, and the two hydrogen atoms are attached to it at an angle of approximately 104.5 degrees. This angle gives water its unique properties and affects its behavior as a solvent, as well as its ability to form hydrogen bonds with other water molecules.



The oxygen atom in a water molecule has a slightly negative charge (δ-) due to its higher electro negativity compared to hydrogen. This creates a partial positive charge (δ+) on each hydrogen atom. As a result, water molecules are polar, with the oxygen end being more negatively charged and the hydrogen ends being more positively charged. This polarity allows water molecules to attract and interact with each other through hydrogen bonding, which gives water its high boiling point, high specific heat capacity, and other important properties. Water molecules consist of two hydrogen atoms covalently bonded to a central oxygen atom. The arrangement of atoms in a water molecule is bent or V-shaped, with the oxygen atom having a slightly negative charge and the hydrogen atoms having a slightly positive charge. This polarity and the ability to form hydrogen bonds contribute to the unique properties and behavior of water.

4.3. Chemical bonding in water

Water is polar in nature and a good solvent. Water forms weak bonds with number of polar and non polar molecules. We know the water have properties to form hydrogen bonding due to presence of partially positive and partially negative charge. However, hydrogen atom also covalently bonded to carbon atom, even it do not participate in hydrogen bonding because carbon does not has negative charge. For example, butanol$(CH_3CH_2CH_2CH_2OH)$ has relatively higher boiling point (117 °C) as compare to butane $(CH_3CH_2CH_2CH_3)$, which has boiling point only -0.5 °Cbecause, butanol has hydrogen bonding. The butanol has hydroxyl group and formed hydrogen bond with other molecules. However, hydrogen atom has stabilizing effect with some polar molecules that’s why sugar dissolves readily in water. Hydrogen of water forms that form hydrogen bonding between with hydroxyl groups or carbonyl group of the sugar. The other polar water molecules, such as alcohol, aldehyde and ketones all form hydrogen bonding with water.



4.4. Unique properties of water

Water present in nature in three form liquid, gas, and solid on the basis of temperature. Our body contain about 70 to 90% water because it familiar and iniquitous in nature. Water found in our body in the association with macromolecules and cell organelles that require to biological properties of proteins, nucleic acid as well as membrane, ribosomes and many other components. Water is the simple molecule that forms by the combination of hydrogen and oxygen in 2:1. Water considered as universal solvent. It has molecular formula H_2O, water is reactive substance with usual properties. Water recognizes as good solvent because it is polar in nature. Water ionizes in two forms as hydronium ions and hydroxide ions. Water as molecular form has both partial positive (due to presence of hydrogen in one side of water molecules) and partial negative charge (due to presence of oxygen in one side of water molecules). This nature of water makes it more reactive to with other molecules.

The water molecules have special physical properties. The water molecule as liquid phase has high boiling point, high melting point, high vaporization, specific heat capacity and surface tension compare to other hydride molecules. Water molecules are formed by equal sharing of electron by covenant bonding. It has sp^3hybridization and hydrogen tetrahedral arrangement, this type of arrangement result occurs net dipole in water in which the end of molecule containing the unshared electron has partially positive charge character and the end containing the two hydrogens has partially negative charge character shown in Fig. In addition, hydrogen oxygen bonding as dipolar character due to unequal sharing of electrons between hydrogen and oxygen. However, due to presence of equal partially positive and negative charge in both sides, the resulting net charge in the molecule in zero. Thus, it is known as dipole molecule. The spectroscopic and X rays studies define the precise H-O-H analysis is 104.5^0 a hydrogen oxygen intra-atomic distance is 0.0965 nm.

Due to presence of partial positive charge on hydrogen atom and partially negative charge on oxygen atom, two water molecule approach to closely attached together by electrostatic attraction. Where positive charge of one water molecule (hydrogen atom) attracts toward negative charge of other water molecule (oxygen), same as the partially negative charge of one water molecule oxygen atom attract toward positive charge hydrogen atom of other water molecule. This accompanied by redistribution of the electronic range in both molecules. Thus, this is association of both two-hydrogen atom is called hydrogen bonding. This is only properties that responsible for the great internal cohesion of liquid water. The hydrogen bonding is relatively weak than covalent bonds. Each water molecules have hydrogen bonding to 4 neighbour molecules.

Since, water molecule arrange in tetrahedral arrangement same the neighbour molecule is also had tetrahedral arrangement. The ice which is the form of water also have tetrahedral crystalline lattice in which water molecules attract by hydrogen bonding. The cohesion of water molecules contains as high melting point and high boiling point in in spite of low molecular weight (18 g/mole). The high special heat and high evaporation make it excellence thermal for actively metabolizing cells and tissue.

a. Interaction between water and charge solutes or nonpolar gas:

The molecules that are easily dissolved in water (polar) are generally charged or polar molecules are known as hydrophilic molecules. However, non-polar solvents are poor solvent for polar molecules but they readily dissolve nonpolar molecules such as lipids and wax etc. For example, NaCl (polar) is readily dissolved in water by hydrating and stabilising the Na^+ and Cl^- ions. Polar molecules such as glucose, glycine, aspartic acid and lactic acid etc easily dissolve in water. O_2, $\mathrm{N}_2$and CO_2 gases are non-polar in nature, but CO_2 gas forms carbonic acid ($\mathrm{H}_2\mathrm{CO}_3$) in aqueous solution. The two the gas NH_3 and $\mathrm{H}_2\mathrm{S}$ dissolve in water and have biological role in organism.

b. vander Waals interactions:

They are weak and non specific intrinsic, attractions. It formed when two charge atoms closely stand at 3 to 4 $\mathring{A}$. They are weak and less specific than electrostatic and hydrogen bonding and also have importance in biological system. All types of molecules exhibit van der Waals forces which arise from the attraction of the bounding electron of one atom for the molecules of other. When two atoms are for apart, this is very weak attraction which becomes stronger as the atom closer together.

Ionization of water:

It must be known that lots of properties of water molecules is governs by its uncharged form as ($\mathrm{H}_2\mathrm{O}$). While to understand their properties we should know the ionization of water as to hydrogen ion $[\mathrm{H}^{\mp}]$ and hydroxide ion $[\mathrm{OH}^{-}]$. In this ionization, we can see through reversible ionization of water molecules that yield a hydrogen ion and a hydroxide ion:

$H_2O \leftrightharpoons H^+ + OH^-$(i)

This reversible ionization is crucial to the role of water in cellular functions. In this reversible reaction, the equilibrium of H_2O and it's ionized formed is determine by it equilibrium constants as shown in Eq. (ii).

$$A + B \leftrightharpoons C + D \qquad \text{(ii)}$$

Equilibrium constant can be defined in terms of concentration of reactant (A & B) and product (C & D) present in equilibrium.

$$K_{eq} = \frac{[C][D]}{[A][B]} \qquad \text{(iii)}$$

Where key is equilibrium constant and bracket [] represent concentration of reactant and product. The equilibrium constant is fix and characteristic for given chemical reaction at specific temperature. The $\mathrm{H_2O}$also concentrated at given temp. 25 °Cabout only one of every 10^7molecule in pure water is ionized at any instant. The equilibrium constant for the reversible ionization of water is

$$K_{eq} = \frac{[H^+][OH\text{-}]}{[H_2O]} \qquad \text{(iv)}$$

In pure water at 25 °C, the concentration of water is 55.5 Mole. Thus, value is essentially constant in reaction to the very low concentration of H+ and OH- normally 1 x 10^7 M.

$$K_{eq} = \frac{[H^+][OH\text{-}]}{[55.5\ M]} \qquad \text{(v)}$$

$$(55.5M)(k_{eq}) = [H^+] + [OH^-] = k_w$$

Where k_w denotes the product (55.5 M), (k_w) the ion product of water is 25 °C. The value of k_w is 1.8 x 10^{-16} at 25 °C. Put the value of $k_w$in Eq (v) we found.

$$(55.5M)\ 1.8\,x10^{-16}M = [H^+] + [OH^-] = k_w$$

$$99.9\,x10^{-16}M^2 = [H^+] + [OH^-] = k_w$$

$$1.0\,x10^{-14}M^2 = [H^+] + [OH^-] = k_w$$

Thus, the product $[H^+] + [OH^-]$ in aqueous solution at 25 °C always equal to 1 x 10^{-14} M^2, where are exactly equal concentration of both product $[H^+] + [OH^-]$.

In pure water, the solution is said to be neutral pH. At this pH, the concentration$[H^+] and [OH^-]$ can be calculated from the ion product of water as follows

$$k_w = [H^+] + [OH^-] = [H^+]^2$$

Solution of $[H^+]$ gives

$$H^+ = \sqrt{k_w}\sqrt{1\,x 10^{-14} M^2} = 1\,x 10^{-7} M$$

$$OH^- = 1\ x 10^{-7} M$$

4.5. pH Scale

pH is also refers to potential of hydrogen. pH is a symbol and donates the relative concentration of hydrogen ion in solution of extend form of value 0 to 14, the lower the value, the higher the acidity or the more hydrogen ion concentration. In solution water at 25 °C has a concentration of hydrogen ion of 10-7, the pH therefore, is 7.

H^+ ion of water, k is the basis for the pH scale, it shows the actual concentration of hydrogen ion in aqueous solution in range blew 1.0M H^+ and 1.0 M OH^-.All the biological reactions defined this pH scale.

The pH also defines that pH of a solution as the negative logarithm of concentration of hydrogen ion, thus:

$$pH = \log \frac{1}{H^+} = -\log H^+$$

At mention solution at 25 °C the concentration of H^+ ion found 1 x 10^{-7} M. The pH can be calculated as

$$pH = \log \frac{1}{1\ x\ 10^{-7}} = -\log(1\ x\ 10^7)$$

$$= \log 1.0 + \log 10^7$$

$$= 0 + 7.0$$

$$= 7.0$$

Solutions in which pH = 7.0 are defined as neutral. Solutions with pH < 7.0 are called "acidic," and solutions in which pH > 7.0 are called "basic." In **Fig. 2.16** are shown the pH Values of some common fluids.

$[H^+]$ **M**	**pH**	**$[OH^-]$** **M**	**pOH***
$10^{-0(1)}$	0	10^{-14}	14
10^{-1}	1	10^{-13}	13
10^{-2}	2	10^{-12}	12
10^{-3}	3	10^{-11}	11
10^{-4}	4	10^{-10}	10
10^{-5}	5	10^{-9}	9
10^{-6}	6	10^{-8}	8
10^{-7}	7	10^{-7}	7
10^{-8}	8	10^{-6}	6
10^{-9}	9	10^{-5}	5
10^{-10}	10	10^{-4}	4
10^{-11}	11	10^{-3}	3
10^{-12}	12	10^{-2}	2
10^{-13}	13	10^{-1}	1
10^{-14}	14	$10^{-0(1)}$	0

4.6. Water as solvent

Water (H_2O) is a molecule composed of two hydrogen atoms and one oxygen atom, with a chemical formula of H_2O. The atomic mass of hydrogen is approximately 1, while that of oxygen is approximately 16. Therefore, the molecular weight of water is approximately 18.015 daltons (Da).

The chemical composition of pure water is therefore:

Two hydrogen atoms (H)

One oxygen atom (O)

This can be represented in a chemical equation as:

$$H_2O = 2H + O$$

Water is an excellent solvent due to its polar nature, which allows it to dissolve many different substances. When a solute is added to water, it can dissociate or form solvation shells around its particles, facilitating the dissolution process. The interaction between the solute and water molecules can be represented by a chemical equation. The groundwater contains dissolved minerals such as calcium, magnesium, and sodium, while surface water may contain dissolved gases such as carbon dioxide and oxygen. The example of table salt (sodium chloride, NaCl) dissolving in water. The chemical equation for this process is as follows:

$$\mathrm{NaCl}\ (s) + H_2O\ (l) \rightarrow \mathrm{Na}^+(aq) + \ \mathrm{Cl}^-(aq)$$

In this equation, NaCl is the solute, and H2O is the solvent (I stands for liquid water). When NaCl is added to water, the crystal lattice of NaCl breaks apart, and the individual Na^+ and Cl^- ions dissociate from each other due to the interactions with water molecules. The arrow represents the direction of the reaction. On the left side, we have solid NaCl (s) and liquid water (l), indicating the initial state. On the right side, we have aqueous Na^+(aq) and Cl^-(aq), representing the dissolved ions in the water (aq stands for aqueous solution). In this equation, the water molecules surround the ions, forming solvation shells through electrostatic interactions. The partially positive hydrogen atoms in water molecules are attracted to the negatively charged chloride ions (Cl^-), while the partially negative oxygen atoms are attracted to the positively charged sodium ions (Na^+).

Some other examples of solutes that can dissolve in water:

Ionic compounds: Water is particularly effective at dissolving ionic compounds due to its polarity. Examples include table salt (sodium chloride, NaCl), potassium nitrate (KNO_3), and magnesium sulfate ($MgSO_4$).

Polar molecules: Water can dissolve other polar molecules by forming intermolecular interactions. Examples include sugar (sucrose), ethanol (ethyl alcohol), and ammonia (NH_3).

Acids and bases: Water can dissolve acids and bases by forming ions through ionization or dissociation. Examples include hydrochloric acid (HCl), sulfuric acid (H_2SO_4), and sodium hydroxide (NaOH).

Gases: Water has the ability to dissolve certain gases, allowing them to be transported in the bloodstream or absorbed by aquatic organisms. Examples include oxygen (O_2), carbon dioxide (CO_2), and ammonia (NH_3).

Some organic compounds: While water is not a universal solvent for nonpolar substances, it can dissolve certain organic compounds with polar functional groups. Examples include alcohols (e.g., methanol, ethanol), aldehydes (e.g., formaldehyde), and organic acids (e.g., acetic acid). Water’s ability to dissolve substances depends on factors such as the nature of the solute, temperature, and pressure. Additionally, some substances may have limited solubility in water or may require specific conditions for dissolution. Water’s versatility as a solvent plays a crucial role in various biological, chemical, and environmental processes, making it essential for life as we know it.

4.6.1. River water:

The chemical composition of river water can vary depending on the location, season, and surrounding environment. However, in general, river water contains the following chemical compounds:

Dissolved ions: In river water, various ions can dissolve, leading to the presence of dissolved salts and minerals. Rivers receive water from various sources, such as rainfall, groundwater, and runoff, which can contain dissolved substances. These ions can affect the water's pH, conductivity, and hardness. Sodium, calcium, magnesium, chloride, bicarbonate,sulfate and nitrate ion are found in the river water. The specific composition of ions in a river can vary depending on factors such as the geology of the area, human activities in the surrounding area, and the flow and mixing of water from different sources

Dissolved gases:

River water can also contain dissolved gases such as oxygen, nitrogen, and carbon dioxide, which are essential for aquatic life and can influence the water's oxygen saturation. Oxygen is essential for aquatic organisms for respiration and plays a vital role in supporting aquatic ecosystems. Carbon dioxide concentration in river water is also influenced by factors such as photosynthesis by aquatic plants and the surrounding landscape's geology. Nitrogen gas can dissolve in river water to a limited extent. Nitrogen gas is not very soluble in water compared to other gases. Methane is a greenhouse gas that can dissolve in river water. It can be produced through microbial activity in the sediments or from the decomposition of organic matter in the water. Other gases, such as hydrogen sulfide (H_2S) and various volatile organic compounds (VOCs), can dissolve in river water depending on specific environmental conditions, pollution sources, or nearby industrial activities. The solubility of gases in water depends on factors such as temperature, pressure, gas concentration, and the specific chemical properties of the gas. Dissolved gases in river water play important roles in supporting aquatic life, nutrient cycling, and overall ecosystem dynamics.

Organic matter:

River water can contain organic matter, such as decaying plant and animal material, which can affect water quality and nutrient availability. Organic matter in river water undergoes decomposition by microbial activity. Bacteria and fungi break down the organic compounds, releasing nutrients and energy. This decomposition process is vital for nutrient cycling, as it releases essential elements such as carbon, nitrogen, and phosphorus that are then available for uptake by aquatic plants and other organisms. Organic matter in river water exists in both particulate and dissolved forms. Dissolved organic matter (DOM) refers to organic compounds that are dissolved in the water column. DOM consists of complex mixtures of organic molecules, including humic substances, proteins, carbohydrates, and dissolved gases. DOM can influence water quality, nutrient availability, and light penetration in the water. Monitoring and managing organic matter in river water are important for assessing ecosystem health, water quality, and the impacts of human activities. Analyzing organic matter concentrations and understanding the dynamics of organic carbon cycling in rivers are key for sustainable management and protection of freshwater resources.

Microorganisms:

River water can also contain microorganisms, such as bacteria and viruses, which can pose health risks if present in high concentrations. Microorganisms in the ocean are vital for maintaining ecosystem health, nutrient cycling, and the overall balance of marine ecosystems. The diversity and abundance of microorganisms in the ocean are incredibly vast, and scientists continue to discover new species and uncover their ecological significance.

Anthropogenic pollutants

Anthropogenic pollutants are human-made pollutants that can contaminate river water and have detrimental effects on aquatic ecosystems and human health. These pollutants can enter rivers through various pathways, including industrial discharges, agricultural runoff, urban stormwater, and improper waste disposal. Here are some common anthropogenic pollutants found in river water. Monitoring and regulation of anthropogenic pollutants in river water are crucial for protecting water quality, preserving aquatic ecosystems, and ensuring the safety of water resources for human use. Implementing effective pollution control measures, promoting sustainable practices, and adopting proper waste management strategies are essential for reducing the impact of anthropogenic pollutants on river water.

The exact chemical composition of river water can vary greatly depending on the specific location and environmental conditions.

4.6.2. Ocean water:

The chemical composition of ocean water is similar to that of river water, but with some important differences due to the ocean's unique characteristics. The major components of seawater include:

Salts:

The primary salt in seawater is sodium chloride (NaCl), commonly known as table salt. It is the most abundant dissolved compounds in seawater are salts, which consist mainly of sodium chloride (NaCl) about 85% of the total dissolved salts, and other ionic compounds such as magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$)).The salinity of ocean water, which refers to the concentration of dissolved salts, is approximately 3.5%. This means that for every 1,000 grams of seawater, about 35 grams are dissolved salts. Besides sodium chloride, other salts found in seawater include magnesium chloride, magnesium sulfate, calcium sulfate, and potassium chloride; among others trace elements are also found. The calcium ions can dissolve in river water comes from the weathering of calcium-containing rocks or the dissolution of calcium salts. However, the magnesium ions present due to weathering of magnesium-rich minerals. In addition, the ions such as bicarbonate ion (HCO_3^-) ions Sulfate ion (SO_4^{--}) and Nitrate ion (NO_3^-) are also found in ocean water through various sources. Salinity is a crucial parameter in oceanography as it affects various physical and chemical properties of seawater, including density, freezing point, and conductivity. It plays a significant role in ocean circulation patterns, the distribution of marine organisms, and the overall functioning of marine ecosystems.

Dissolved gases:

Seawater contains dissolved gases such as oxygen, carbon dioxide, and nitrogen, which are essential for marine life and can influence ocean chemistry and climate. Oxygen dissolves in ocean water through atmospheric exchange at the air-sea interface. Carbon dioxide is a significant gas dissolved in ocean water. It enters the ocean through several sources, including the atmosphere, runoff from land, and biological processes such as respiration and photosynthesis. The ocean acts as a major carbon sink, absorbing a significant portion of the atmospheric carbon dioxide, which plays a crucial role in regulating the Earth's climate. However, small amounts of nitrogen gas can dissolve in seawater, primarily through atmospheric diffusion. Methane concentrations in seawater can vary depending on local geology, temperature, and microbial activity. Other gases that can dissolve in ocean water include nitrogen oxides (such as nitric oxide, NO, and nitrogen dioxide, NO_2), hydrogen sulfide (H_2S), hydrogen (H_2), and various volatile organic compounds (VOCs). The solubility of gases in ocean water depends on factors such as temperature, salinity, pressure, and the specific chemical properties of the gases. The dissolved gases in ocean water play important roles in regulating the Earth's climate, supporting marine life, and influencing various biogeochemical processes in the marine environment.

Trace elements: Seawater contains a variety of trace elements, including iron, manganese, and zinc, which are important for biological processes in the ocean. The percentage of some other elements are such as

- Oxygen (O): Approximately 85.84% of the atoms in ocean water are oxygen.
- Hydrogen (H): Approximately 10.82% of the atoms in ocean water are hydrogen.
- Chlorine (Cl): Approximately 1.94% of the atoms in ocean water are chlorine.
- Sodium (Na): Approximately 1.08% of the atoms in ocean water are sodium.
- Magnesium (Mg): Approximately 0.1292% of the atoms in ocean water are magnesium.
- Sulfur (S): Approximately 0.091% of the atoms in ocean water are sulfur.
- Calcium (Ca): Approximately 0.04% of the atoms in ocean water are calcium.
- Potassium (K): Approximately 0.039% of the atoms in ocean water are potassium.

Iron is an essential trace element in ocean and it is vital micronutrient for marine phytoplankton, which are the primary producers in the marine food chain. Zinc, manganese and cobalt is another trace element present in ocean water is useful full in various biological processes, including enzyme function, growth, and nitrogen-fixing bacteria of various organisms. Copper is a trace element that is important for enzymatic reactions in marine organisms. Molybdenum is a trace element that plays a role in nitrogen fixation by certain bacteria and component of nitrogenase enzymes. Selenium is a trace element that can be found in ocean water. The concentrations of these trace elements can vary depending on factors such as water temperature, salinity, depth, and the influence of terrestrial inputs, hydrothermal vents, and other geological processes. Trace elements are essential for maintaining the health and functioning of marine ecosystems, and their availability can have significant impacts on marine organisms and biogeochemical cycles.

Organic matter:

Seawater contains dissolved organic matter, such as sugars and amino acids, which are important nutrients for marine life. Dead organisms, including phytoplankton, zooplankton, fish, and other marine animals, contribute to the organic matter in the ocean. Organic matter in ocean water consists of a complex mixture of compounds, including proteins, carbohydrates, lipids, nucleic acids, and other organic molecules. The composition can vary depending on factors such as the source of organic matter, the stage of decomposition, and environmental conditions. The percentage of organic matter in ocean water can vary significantly depending on location, depth, and the presence of specific marine ecosystems. On average, organic matter concentrations in the open ocean range from about 0.1 to 0.5 milligrams per liter (mg/L) or 0.01% to 0.05% by weight. Understanding the dynamics of organic matter in ocean water is crucial for assessing marine ecosystem health, biogeochemical cycling, and the impacts of climate change on the oceans. Monitoring and studying the distribution, composition, and fate of organic matter contribute to our understanding of the complex interactions within marine environments.

Microorganisms

Ocean water contains a diverse range of microorganisms that play critical roles in marine ecosystems. These microorganisms are essential for nutrient cycling, primary production, decomposition, and overall ecosystem functioning. The microorganism such as phytoplankton, Bacteria, Archaea, Viruses, Protists and Fungi are present in ocean water. The diversity and abundance of microorganisms in the ocean are incredibly vast, and scientists continue to discover new species and uncover their ecological significance. Microorganisms in the ocean are vital for maintaining ecosystem health, nutrient cycling, and the overall balance of marine ecosystems.

Anthropogenic pollutants: Like river water, seawater can also be contaminated by various anthropogenic pollutants, including plastics, heavy metals, and industrial chemicals, which can harm marine life and pose a threat to human health.

The chemical composition of ocean water is relatively stable and does not vary much from place to place. However, the salinity, temperature, and nutrient levels can vary greatly depending on the location and season, and these variations can have a significant impact on the ocean ecosystem.

4.6.3. Lake water:

Lake water is a vital component of the Earth's hydrological cycle, playing a crucial role in sustaining ecosystems and human activities. Lakes are bodies of freshwater that vary in size from small ponds to vast inland seas. The water within these bodies is dynamic and complex, influenced by a multitude of physical, chemical, and biological processes. In this essay, we will explore the characteristics of lake water, its importance, the factors affecting its quality, and the challenges it faces in the modern world.

The water in lakes is predominantly freshwater, with low salinity levels compared to seawater. It originates from various sources, including precipitation, surface runoff, groundwater, and inflowing rivers and streams. Precipitation, in the form of rain and snow, is a primary source of freshwater input to lakes. This water carries nutrients and dissolved substances from the atmosphere and surrounding landscapes, which contribute to the lake's chemistry.

Lakes are not stagnant bodies of water; they are in a constant state of flux. Water movement within lakes is driven by various factors, including wind, temperature gradients, and the Earth's rotation. This circulation can lead to the stratification of the water column into distinct layers, typically the epilimnion (surface layer), metalimnion (thermocline), and hypolimnion (deep layer). The different layers have different temperature and oxygen profiles, which influence the distribution of aquatic life.

Lake water is essential for both natural ecosystems and human societies. Ecosystems in and around lakes are highly dependent on the availability and quality of lake water. Aquatic plants, algae, and phytoplankton flourish in the well-lit, nutrient-rich epilimnion. These primary producers form the base of the food web, supporting a diverse range of organisms, from zooplankton to fish and waterfowl. Many bird species rely on lakes for breeding and feeding grounds, making them critical habitats for avian biodiversity.

Beyond their ecological significance, lakes serve as important water resources for human communities. They provide drinking water, irrigation for agriculture, recreational opportunities, and sources of hydropower. In many parts of the world, lakes also play a role in transportation and trade. For example, the Great Lakes in North America are interconnected water bodies that have historically been vital for shipping and commerce.

However, the quality of lake water is susceptible to a variety of factors. Pollution from human activities, such as industrial discharge, agriculture, and urban development, can introduce contaminants into lakes. Nutrient runoff, particularly from fertilizers, can lead to eutrophication, a process in which excessive nutrients cause algal blooms, oxygen depletion, and the decline of fish populations. Additionally, invasive species can disrupt the natural balance of lake ecosystems, outcompeting native species and altering the food web.

Climate change is also having a profound impact on lake water. Rising temperatures can affect the stratification patterns of lakes, potentially leading to decreased oxygen levels in deeper layers, which can harm fish populations. Changes in precipitation patterns and increased evaporation can alter water levels, affecting the overall health of lake ecosystems. Additionally, the melting of glaciers and ice caps contributes to rising lake levels in some regions, increasing the risk of flooding.

The chemical composition of lake water can vary depending on the location, size, depth, and surrounding environment. However, in general, lake water contains the following chemical compounds:

Dissolved ions: Like river water and seawater, lake water contains various dissolved ions such as calcium, magnesium, sodium, and potassium, which are derived from the surrounding rocks and soils. These ions can affect the water's pH, conductivity, and hardness.

Elements: Elements in a lake refer to the various chemical elements that are present in its water and sediments. These elements play essential roles in the lake's ecosystem and influence its overall chemistry and biological processes. The lake water contain several essential elements such as Carbon, Nitrogen, Phosphorus, Oxygen, Calcium, Magnesium, and Sodium, In addition it may contain trace amounts of various elements, including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and others. These elements are required in small quantities by organisms and can have important biological functions but can become toxic at high concentrations.

Dissolved gases: Lake Water can also contain dissolved gases such as oxygen, nitrogen, and carbon dioxide, which are essential for aquatic life and can influence the water's oxygen saturation. Oxygen is one of the most important dissolved gases in lake water as it is vital for the survival of aquatic organisms. The percentage of dissolved oxygen can range from about 0% to 20%, with higher concentrations typically found near the water's surface and lower concentrations at greater depths. The percentage of dissolved carbon dioxide can range from less than 1% to a few percent, depending on factors such as photosynthesis rates, microbial activity, and water temperature. Nitrogen gas is relatively insoluble and tends to exist as a dissolved gas in lower concentrations in lake water. Methane is a greenhouse gas that can be produced in oxygen-depleted sediments or by certain bacteria in the lake.

Organic matter: Lake water can contain organic matter, such as decaying plant and animal material, which can affect water quality and nutrient availability. The organic matter in a lake plays a crucial role in its ecological functioning. It serves as a source of nutrients for the organisms living in the lake, providing energy for their growth and metabolism. As organic matter decomposes, it releases essential elements like carbon, nitrogen, and phosphorus into the water, which are utilized by various organisms. The organic matter also contributes to the sedimentation process in lakes. Over time, organic matter settles to the lake bottom, accumulating as sediment. This sediment can serve as a historical record of past environmental conditions and can provide insights into the lake's long-term ecological changes. Other gases such as hydrogen (H_2), hydrogen sulfide (H_2S), and various volatile organic compounds (VOCs) may be present in lake water

Microorganisms: Microorganisms in lakes refer to the diverse range of microscopic organisms that inhabit lake ecosystems. These microorganisms play critical roles in the functioning of the lake and have significant impacts on nutrient cycling, water quality, and overall ecosystem health. The bacteria and viruses, which can pose health risks if present in high concentrations in lake water. These microorganisms interact with each other and with the physical and chemical conditions of the lake to form complex and dynamic microbial communities. They are integral to the functioning and stability of lake ecosystems, impacting water quality, carbon cycling, and the overall biodiversity of the system.

Anthropogenic pollutants: Lake water can be contaminated by various anthropogenic pollutants, including pesticides, industrial chemicals, and heavy metals, which can pose a threat to human and aquatic health.

The exact chemical composition of lake water can vary greatly depending on the specific location and environmental conditions. The size and depth of the lake, the degree of water circulation, and the presence of inflowing streams or groundwater sources can all influence the chemical composition of lake water.

Conservation and management of lake water are critical to ensuring the long-term sustainability of these ecosystems. Efforts to reduce nutrient pollution, control invasive species, and mitigate the effects of climate change are essential. Many countries have implemented water quality regulations and monitoring programs to protect their lakes. Lake water is a dynamic and vital component of the Earth's freshwater resources. It sustains ecosystems, supports biodiversity, and serves as a valuable resource for human societies. However, it faces numerous challenges, including pollution, invasive species, and the impacts of climate change.

Conservation and management efforts are crucial to protect the quality and sustainability of lake water for current and future generations.

Effect of climate change on Lake Water bodies

Climate change is having a profound impact on lake water and the ecosystems that depend on it. Here are some of the key effects of climate change on lake water:

1. **Temperature Changes:** One of the most noticeable effects of climate change on lake water is rising temperatures. As global temperatures increase, lakes warm up, which can disrupt the natural temperature stratification in lakes. This can affect the distribution of aquatic life and lead to shifts in the composition of species within the lake.
2. **Altered Thermal Stratification:** Climate change can disrupt the typical seasonal patterns of thermal stratification in lakes. Normally, lakes have distinct layers with different temperatures. Climate-induced changes can lead to longer periods of thermal stratification, affecting the distribution of oxygen and nutrients in the water column. This can have significant consequences for the health of the lake and its inhabitants.
3. **Reduced Ice Cover:** Warming temperatures lead to reduced ice cover on many lakes, especially in the winter. This can impact the physical and biological processes in lakes. For example, less ice cover can result in increased evaporation and decreased water levels, affecting the overall health of the ecosystem.
4. **Algal Blooms:** Higher temperatures and increased nutrient runoff due to climate change can lead to more frequent and severe algal blooms in lakes. These blooms can disrupt the balance of the ecosystem, decrease water quality, and have harmful effects on aquatic life and human health.
5. **Changes in Precipitation Patterns:** Climate change can alter precipitation patterns, leading to more intense rainfall events and changes in the timing and amount of snowmelt. This can result in fluctuations in lake levels and increased risks of flooding in some regions, while other areas may experience lower lake levels and droughts.
6. **Impact on Aquatic Life:** Climate change can affect the life cycles and habitats of fish and other aquatic species. For example, changes in temperature and food availability can impact fish spawning and migration patterns. Some species may be more resilient to these changes, while others could face declining populations or even extinctions.

7. **Spread of Invasive Species:** The warming of lake water can create more favorable conditions for invasive species. Invasive aquatic species, which are often more resilient to changing environmental conditions, can outcompete native species, disrupt the food web, and negatively impact the overall health of the lake ecosystem.
8. **Increased Wildfire Risk:** Climate change contributes to more frequent and intense wildfires, which can have indirect effects on lake water quality. Wildfires can lead to the erosion of soil and the release of ash and debris into nearby lakes, increasing the risk of sedimentation and nutrient loading, which can harm the water quality.
9. **Impact on Water Supply:** Many communities rely on lakes as a source of drinking water. Changes in lake water quality and availability due to climate change can affect water supply systems, potentially requiring costly adjustments to ensure safe and reliable drinking water.
10. **Socioeconomic Impacts:** Climate change can affect the recreational and economic value of lakes. Changes in water quality and the abundance of certain species can impact tourism, fishing, and other industries that depend on healthy lake ecosystems.

4.4. Difference between river, ocean and lake water

While river, ocean, and lake water all contain similar chemical components, there are some differences in their chemical composition and physical characteristics that distinguish them from each other. Here are some key differences:

Salinity: One of the most significant differences between river, ocean, and lake water is their salinity. Ocean water is highly saline due to the large amount of dissolved salts, while river water is typically low in salinity. Lake water can vary in salinity, depending on its location and surrounding environment.

Dissolved oxygen: The amount of dissolved oxygen in water can vary depending on various factors, including temperature, depth, and photosynthesis. Ocean water typically has a higher concentration of dissolved oxygen than river or lake water due to the high rate of photosynthesis by marine plants and algae.

Nutrient levels: Rivers and lakes typically have higher levels of nutrients such as nitrogen and phosphorus due to the surrounding land and vegetation. Ocean water may have lower levels of nutrients in some areas due to the limited availability of these nutrients.

Water flow: Rivers and oceans have a continuous flow of water, while lakes may have limited water flow or be stagnant in some areas. This can affect the water's chemical composition and nutrient levels.

Anthropogenic pollution: Rivers and lakes are more vulnerable to anthropogenic pollution due to the surrounding human activity, such as agricultural runoff and industrial discharge. While the ocean is not immune to pollution, it has a larger volume of water that can dilute contaminants more effectively.

Overall, while river, ocean, and lake water share many similarities in their chemical composition, their physical and environmental characteristics can result in distinct differences in their water quality and composition.

4.7. Water as solvent

Water is a highly versatile solvent due to its unique chemical and physical properties. Water's polarity and ability to form hydrogen bonds make it an excellent solvent for a wide range of chemical compounds. However, Water is a remarkable solvent that plays a critical role in various chemical and biological processes. Its unique properties make it an ideal medium for dissolving a wide range of substances, from simple salts to complex organic molecules. This versatility as a solvent is essential for life on Earth and has far-reaching implications in many fields of science and technology.

One of the key characteristics of water as a solvent is its polarity. Water molecules consist of two hydrogen atoms bonded to one oxygen atom, and the oxygen atom is more electronegative than hydrogen, creating an uneven distribution of charge within the molecule. This results in a partial negative charge on the oxygen atom and partial positive charges on the hydrogen atoms. These partial charges give rise to a strong electrostatic attraction between water molecules, forming hydrogen bonds.

Hydrogen bonding is a crucial factor that enables water to dissolve a wide range of substances. When a solute, such as a salt or a sugar, is introduced into water, the partially charged regions of water molecules interact with the solute molecules. For example, in the case of table salt (sodium chloride), the positively charged sodium ions are attracted to the partially negative oxygen atoms of water, while the negatively charged chloride ions are attracted to the partially positive hydrogen atoms. The result is the dissociation of salt into its constituent ions, making it soluble in water.

The ability of water to dissolve polar and ionic compounds extends to a wide array of substances. This is essential in biological systems, as many biomolecules, such as proteins and nucleic acids, are polar or charged. Water's solvent properties are crucial for the proper functioning of these biomolecules, as it allows them to interact and carry out their biological functions.

Furthermore, water's high heat capacity and thermal conductivity make it an excellent solvent for temperature regulation in living organisms. It can absorb and release heat without significant temperature changes, helping to maintain stable conditions for biochemical reactions. Additionally, water's high specific heat capacity ensures that it can buffer temperature changes in the environment, which is crucial for maintaining the stability of ecosystems and supporting life.

Water's solvent properties also have a significant impact on the environment. It plays a vital role in the cycling of nutrients, such as nitrogen and phosphorus, through the natural world. It dissolves these essential nutrients from rocks and minerals, making them available for plant uptake and, subsequently, for consumption by animals. Water's solvent properties also influence the movement of pollutants and contaminants in the environment, affecting water quality and ecosystems.

In industry and technology, water's solvent capabilities are leveraged in various ways. It is used as a solvent in chemical processes, such as in the production of pharmaceuticals and in the development of new materials. Water is also a common medium for the extraction of valuable compounds from natural sources, such as coffee and tea, and in the manufacturing of food products.

Water can dissolve a wide variety of solutes, including ionic compounds, polar molecules, and some nonpolar molecules that have polar functional groups. This makes it an excellent solvent for many biological and chemical processes.

Water has a high heat capacity, meaning it can absorb a lot of heat before its temperature increases. This helps to regulate the temperature of aqueous solutions and allows them to remain stable.

Water is the most abundant substance on Earth and is readily available in most environments, making it a convenient and accessible solvent.

In conclusion, water's role as a solvent is a result of its unique molecular structure and properties, particularly its polarity and ability to form hydrogen bonds. These characteristics allow it to dissolve a wide range of substances, making it an essential component of life on Earth and a crucial factor in various scientific and industrial processes. Water's solvent properties have profound implications in fields ranging from biology to environmental science and technology, highlighting its central role in shaping our world.

4.8. Summary

Water is a unique and essential substance on Earth with many important physical and chemical properties. Water is a polar molecule, meaning it has a partial positive charge on one end and a partial negative charge on the other. This polarity allows water molecules to attract and interact with other polar molecules or ions, making it an excellent solvent for many chemical compounds.Water molecules can form hydrogen bonds with other polar molecules or ions, increasing their solubility in water and creating unique physical properties such as high surface tension and a high heat capacity.Water has a high heat capacity, meaning it can absorb a lot of heat before its temperature increases. This property helps to regulate temperature and maintain a stable environment, particularly in aquatic systems.Water has a high surface tension, which allows it to form drops and maintain the shape of objects floating on its surface. This property is also important for capillary action in plants and the formation of water droplets in the atmosphere.Water is most dense at 4°C, which means that as it cools or warms, it becomes less dense. This property is important for the maintenance of aquatic ecosystems and global ocean currents.Water has strong adhesive and cohesive properties, which allow it to stick to other surfaces and form a continuous column in plants. This property is also important for capillary action and the formation of droplets.Water can dissolve a wide variety of solutes, including ionic compounds, polar molecules, and some nonpolar molecules that have polar functional groups. This makes it an excellent solvent for many biological and chemical processes. These properties make water a unique and essential substance for life on Earth and a fundamental part of many chemical and physical processes.

4.9. Terminal question

Q.1: Write the unique properties of water? Discuss the nature of water as a solvent.

Answer: ---

Q.2: Discuss the chemical composition of water.

Answer: ---

Q.3: Discuss the polarity of water and its application.

Answer: ---

Q.4: How you can say that water is essential for life?

Answer: ---

Q.5: Discuss the role of water in living organism.

Answer: ---

Q.6: Discuss the chemical composition of river and ocean water.

Answer: ---

4.10. Further suggested readings

1. Environmental Science, Subhas Chandra Santra, new central book agency, 3rd Edition, 2011.
2. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.
3. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd.
4. Textbook of Environmental Chemistry and Pollution Control, S.S.Dara and D.D. Mishra, S Chand & Co Ltd.

Unit-5: Water Pollution

Contents

5.1. Introduction

Water is essential for the existence of all life forms. The major part of water on earth is marine water which cannot be used without processing by human beings. The only available fresh water which could be used for drinking purposes arises from the ground water, lakes and streams etc. The percent volume of it, however, is sufficient to cater the need of the living beings, provided it would have been of high quality. However, the water pollution is one of the most serious environmental problems. Water become polluted when water is contaminated by such substances as human and animals wastes, toxic industrial chemicals, agriculture residues, oil and heat. Most of our water bodies such as ponds, lakes, streams, rivers, seas, oceans, underground water resources like tube well, bore well have become polluted due to urbanization, industrial growth and other man made problems.The problem of water pollution is due to discharge of domestic and industrial wastes into aquatic systems like rivers, ponds, lakes, seas, oceans and estuaries has become as serious problem in our country. Most of our rivers and fresh water streams which pass near the major cities, townships or other human dwellings are polluted by industrial wastes or effluents. Our all major rivers are polluted either by industrial effluents or by sewage or domestic waste water. Most of our holy rivers such as Ganga, Godawari, Yamuna and many others have been turned into an open sewer. The sewage, industrial effluents containing toxic chemicals and heavy metals are responsible for various diseases like enteric disorders, typhoid, cholera, dysentery, dysfunction of kidney, liver, reduction in haemoglobin, mental retardation. Fluoride causes knock-knee syndrome i.e. pain in the bones and joint and outward bending of legs from knees, mottling. Methyl mercury causes minimata disease.Water gets polluted naturally as well as artificially or man-made causes. For example fluoride a strong pollutant, which causes knock-knee disease, occurs naturally in water bodies but it also results from industrial activities such as ceramic industries, phosphate fertilizer plants and aluminum factories. In India nearly 84% of water is used in agricultural sectors, 12% in industrial sector and 4% in domestic sector. Even after 50 years of independence. Indian is not fortunate to obtain pure and safe drinking water. Water problem is one of the most important crises on global as well as national level. More than 60% of Indian populations do not have clean safe and pure water to drink. The polluted waters are turbid, unpleasant bad smelling, unfit for bath and washing or other purposes. They are harmful and are sources of number of diseases such as cholera, dysentery, typhoid etc. Polluted water may look clean or dirty but contains germs, chemicals and other harmful toxic materials that can causes inconvenience, illness or death.

Objectives

- To discuss the water pollution and its types
- To discuss marine and oil pollution
- To discuss the water quality parameters like, COD, BOD, DOC and TDS etc.
- To discuss the control of water pollutions

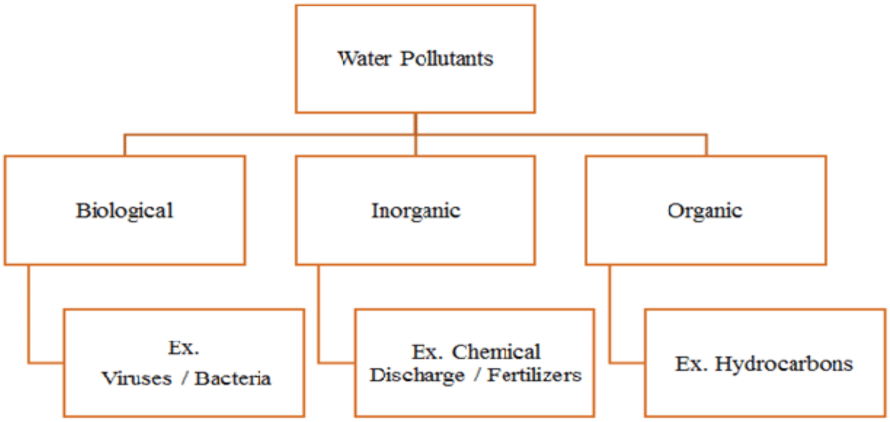
5.2. Water pollution

Water pollution is the contamination of water by pollutants such as bacteria, parasites, chemicals, and trash like plastic. Water pollution refers to the contamination of water bodies, such as lakes, rivers, oceans, and groundwater, by harmful substances or pollutants. **The main types of water pollution include groundwater pollution, surface water pollution, suspended matter, oil spillages, microbiological pollution, chemical water pollution, thermal pollution, and oxygen-depletion pollution. All of these can cause pollutants and contaminants to enter our waterways.**

Water is everywhere; it covers 70% of the Earth’s surface. It is also the most basic resource of survival, supporting all life and ecosystems on our planet. After contaminated air pollution, water pollution is the most common type of pollution, therefore, understanding what water pollution is, and its effects are essential to improving water quality. However, not all types of water pollution come from the same source, so identifying where the pollution comes from is key to preventing and combating water pollution. Water pollution is defined as

“*The addition of any substance to water, changing physical and chemical characteristic of water in any way which interferes with its use for legitimate purpose*”

Water is a contamination of streams, lakes, seas, underground water or oceans by substances, which are harmful for living beings.



Water may be called polluted when the following parameters stated below reach beyond a specified concentration in water.

i. **Physical parameters**:Colour, odour, turbidity, taste, temperature and electrical conductivity constitute the physical parameters and are good indicators of contamination. For example, colour, turbidity etc.

ii. **Chemical parameters:** These include the amount of carbonates, sulphates, chlorides, fluorides, nitrates, and metal ions. These chemicals form the total dissolved solids, present in water.

iii. **Biological parameters**: The biological parameters include matter like algae, fungi, viruses, protozoa and bacteria. The life forms present in water are affected to a good extent by the presence of pollutants. The pollutants in water may cause a reduction in the population of both lower and higher plant and animal lives. Thus, the biological parameters give an indirect indication of the amount of pollution in water.

Source of water pollution

Water pollution occurs in many forms, from a wide range of sources. Agriculture may contribute to water pollution from feedlots, pastures, and croplands. Mining, petroleum drilling, and landfills may also be major sources of water pollution. Other water pollution sources, related to humans, are sanitary sewers, storm sewers, industry, and construction. The surface water pollution has a number of sources and can be categorized into following two:

1) **Point and Non-point Sources:**

The well-defined sources that emit pollutants or effluents directly into different water bodies of fresh water are called point sources. Domestic and industrial waste are examples of this type. On the other hand, the non-point sources of water pollution are scattered or spread over large areas. This type of source delivers pollutants indirectly through environmental changes and account for majority of the contaminants in streams and lakes.

2) Natural and Anthropogenic Sources:

An increase in the concentration of naturally occurring substances is also termed pollution. The sources of such an increase are called natural sources. Siltation (which includes soil, sand and mineral particles) is one such natural source.

Point sources are distinct and specific, for example, sewage from specific industry, domestic sewage, etc. Since, these sources are identifiable, they can easily be monitored whereas the nonpoint sources are scattered and depend on certain natural and artificial factors, for example, surface runoff like rivers, runoff from roads, streets etc.

Water contamination

Contamination refers to the introduction or presence of impurities, pollutants, or harmful substances in a material, environment, or organism where they are not naturally or normally found. It implies the alteration or degradation of the original state or quality of something by the addition of unwanted or undesirable elements. Contamination implies the unwanted presence of substances or elements that can cause harm, reduce quality, or compromise the integrity of a system, material, or organism. Preventing and managing contamination is essential to maintain safety, protect the environment, and safeguard human health. Contamination can occur in various contexts such as environmental contamination, food contamination, contamination in healthcare, microbial contamination and chemical contaminations etc.

Water contamination refers to the presence of harmful substances or pollutants in water bodies, making it unsafe for various uses, including drinking, agriculture, and aquatic life. Water can become contaminated through natural processes or as a result of human activities. Here are some common sources and types of water contamination:

- **Microbial Contamination:** Water can be contaminated with microorganisms such as bacteria, viruses, and parasites, which can cause waterborne diseases.
- **Chemical Contamination:** Water can become contaminated with harmful chemicals, including heavy metals (such as lead, mercury, and arsenic), industrial pollutants, pesticides, fertilizers, pharmaceuticals, and toxic substances.
- **Nutrient Contamination**: Excessive levels of nutrients, particularly nitrogen and phosphorus, can lead to water contamination. This is often caused by agricultural runoff, sewage discharges, or excessive use of fertilizers.
- **Radioactive Contamination:** Radioactive substances can contaminate water sources through nuclear accidents, improper disposal of radioactive waste, or mining activities.
- **Oil and Chemical Spills**: Accidental or deliberate releases of oil and hazardous chemicals into water bodies can cause severe water contamination.
- **Sediment Contamination**: Sediments in water bodies can carry pollutants such as heavy metals, pesticides, and other contaminants.
- **Thermal Pollution:** Discharge of heated water from industrial processes or power plants can raise the temperature of water bodies, leading to thermal pollution.

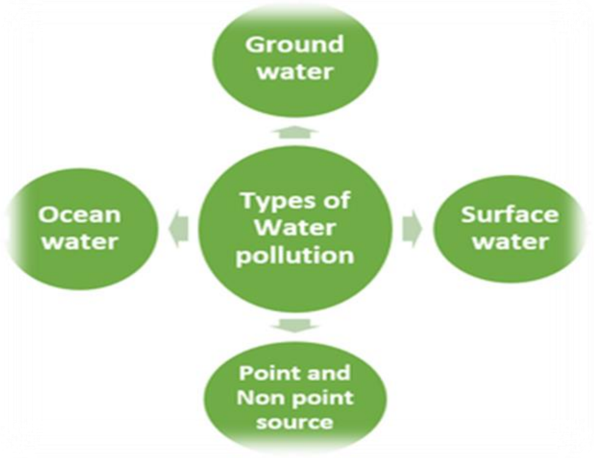
Water contamination poses significant risks to human health, ecosystems, and the environment.

Types of water pollution

Water pollution can be categories into two types

i. ***Fresh water pollution***
ii. ***Marine water pollution***

The fresh water pollution may be further categories into surface water pollution and ground water pollution. If pollutant enters in a lake, pond or river is known as surface water pollution and if pollutants find its way into aquifer, along with water of percolation can deteriorate ground water pollution. The fresh water bodies have very low salt content always less than 5 ppt (parts per thousand). The marine water salt content is between 35 ppt or above. The Estuaries and brackish water having salts content between 5 to 35 ppt. Thus, the pollution of oceans, seas, estuaries, salt marshes are known as marine pollution or ocean pollution.



Apart that the water pollution may be categories that based on origin of water pollutants

- **Industrial Water Pollution:** Industrial activities release a wide range of pollutants into water bodies. These can include toxic chemicals, heavy metals, organic compounds, and wastewater. Industries such as manufacturing, mining, power plants, and chemical processing contribute to industrial pollution.
- **Agricultural Water Pollution:** Agricultural practices often lead to water pollution through the use of fertilizers, pesticides, and herbicides. These substances can run off from fields and enter nearby water bodies, causing eutrophication, algal blooms, and harming aquatic life.
- **Municipal And Domestic Water Pollution**: Sewage and wastewater from households and urban areas can contaminate water bodies if not properly treated. This pollution includes organic waste, nutrients, pathogens, and chemicals from detergents and cleaning products.

- **Thermal Water Pollution:** Discharge of heated water from industrial processes or power plants can raise the temperature of water bodies, negatively impacting aquatic ecosystems. High temperatures reduce dissolved oxygen levels and affect the survival and reproduction of aquatic organisms.
- **Marine Debris Water Pollution:** Plastics, metals, glass, and other solid waste materials that end up in water bodies contribute to marine debris. These materials can harm marine life through ingestion, entanglement, and disruption of ecosystems.
- **Nutrient Pollution Water Pollution**: Excessive nutrients, such as nitrogen and phosphorus, entering water bodies can cause eutrophication. This process leads to excessive algae growth, oxygen depletion, and the death of aquatic organisms.
- **Acid Rain Water Pollution:** Acid rain, primarily caused by air pollution from burning fossil fuels, can lead to the acidification of water bodies when it falls into lakes, rivers, or oceans. Acidic water can harm aquatic organisms and disrupt the ecological balance.
- **Radioactive Pollution:** Discharge of radioactive substances from nuclear power plants, mining activities, or improper disposal of radioactive waste can contaminate water bodies, posing serious health risks to both humans and aquatic life.
- **Groundwater Pollution**: Underground sources of water, such as aquifers, can become polluted by contaminants that seep through the soil, such as agricultural chemicals, industrial pollutants, and leaking underground storage tanks.

Classification of water pollutants

- Organic water pollutant:
- Inorganic water pollutant
- Pollution due to industrialization
- Radioactive pollution
- Thermal

i. Organic water pollutant

Organic water pollutants refer to various types of chemical compounds derived from or containing carbon that can contaminate water bodies. These pollutants can come from both natural and anthropogenic (human) sources and pose a significant threat to aquatic ecosystems and human health. The examples of organic water pollutants such as pesticides, industrial chemicals, petroleum products, pharmaceuticals and personal care products (PPCPS), polychlorinated biphenyls (PCBS), chlorinated solvents, chlorinated hydrocarbons, synthetic organic dyes.

ii. Inorganic water pollutant

Inorganic water pollutants refer to chemical substances that do not contain carbon in their molecular structure. These pollutants can originate from both natural and human activities and can have significant impacts on water quality and ecosystem health. Here are the examples of inorganic water pollutants like Heavy Metals (lead, mercury, arsenic, cadmium, and chromium), Nutrients (nitrogen and phosphorus), Acids and Bases, Salts (sodium chloride (table salt), calcium chloride, and potassium chloride), Toxic Inorganic Compounds (chemical compounds of arsenic, selenium, and mercury) and Sediments and Suspended Solids etc.

iii. Pollution due to industrialization

Industrial water pollutants refer to a wide range of contaminants that are released into water bodies as a result of industrial activities. These pollutants can have adverse effects on water quality, aquatic ecosystems, and human health. Some examples of industrial water pollutants are Heavy Metals, Organic Chemicals, solvents, pesticide, herbicides, Acids and Bases, Nutrients, Suspended Solids, and Pharmaceutical and Chemical Residues etc.

iv. Radioactive pollution

Radioactive water pollutants are contaminants that contain radioactive elements or isotopes and can contaminate water bodies. These pollutants can have severe implications for human health and the environment due to the harmful radiation they emit. Some examples of radioactive water pollutants like radionuclides, tritium, strontium-90, cesium-137, iodine-131, radon, plutonium and other transuranic elements etc.

v. Thermal

Thermal water pollutants, also known as thermal pollution, refer to the release of heated water into natural water bodies, such as rivers, lakes, and oceans. This increase in water temperature can have significant impacts on aquatic ecosystems and organisms. Even a slight increase in temperature can have detrimental effects on aquatic organisms. Temperature-sensitive organisms, such as fish, invertebrates, and plants, may be particularly vulnerable to thermal pollution.

5.2.1.Marine pollution

Marine pollution refers to the contamination of the Earth's oceans and other bodies of water by various pollutants. It is a significant environmental issue that poses threats to marine ecosystems, aquatic life, and human health. The marine pollution occurs when harmful, or potentially effects result from the entry of chemicals, particles, industrial, agricultural, and residential waste, noise, or the spread of invasive organism into the ocean waters. About 71% of the earth surfaces are covered with oceans. Ocean is the ultimate sources or sink of natural and manmade pollutants. In addition to pollutant entering the ocean through rivers, the ocean pollution consist of navigational discharge of oil, detergents, sewage, garbage and radioactive waste, offshore oil mining, oil spills and volcanic eruption. Marine pollution observed in coastal environments occurs mainly due to anthropogenic activities being conducted on the coast and on land adjoining the ocean environment. However the major part of marine pollution comes from the land i.e. dumping of garbage and sewage (30%), through the atmosphere as air pollutants (20%), farm runoff (20%), maritime transportation (10%) as well as industrial wastewater (10%). The consequences of offshore drilling and liter make up for the rest (10%). In addition some other main sources of marine pollutants are such as

- **Surface runoff**: the surface runoff is the main contribute of marine pollutants because the surface runoff water brings lots of different waste material form land to ocean water which consist solid waste, garbage, agriculture and industrial effluents etc. However, these runoffs contain high amount of phosphorous and nitrogen from agricultural and industrial sources. It can lead to the problem of eutrophication in which influx of nutrients causes ‘algal blooms’ and imbalance in the marine ecosystem. Dust particles coming from metal ore and metal mines, also wash away in the rivers. Large chunks of plastics dumped in oceans are the main killer of life in the ocean and may take up to 450 years to degrade. Micro–plastics (size < 5 mm) has been reported in deep-sea sediments and surface waters of Southern Ocean. Runoff water contains harmful contaminants including fertilizers, pesticides, petroleumand other forms of soil pollutants that contaminate the ocean. Sewage or other polluting substances flow through the rivers, or drainages directly into the ocean. Minerals and substances from mining activities also move to the oceans through this pathway. The discharge of other chemical nutrients into the ocean's ecosystem can cause reductions in oxygen levels, affect plant life, decline in the marine water quality itself

- **Atmospheric pollution:**The atmospheric pollutants also contribute in the marine pollution by adding of different suspended particulate matter and green house gases. The increased concentration of CO2 in the atmosphere contributes to ocean acidification as a secondary consequence. Combustion processes produce a significant amount of SO_2 and NOx which will increase the occurrence of acid rain.
- **Ships:** Ship's engines along with incineration of garbage produce CO2, SO2 and NOx, which also contribute to warming.
- **Ballast water:** During unloading of cargo certain amount of oil remains adhered to the walls of container and this may amount to 800 metric ton in a 200,000 metric ton tanker.
- **Bilge water:** Bilge is a specific compartment, designed to capture all water (from rough seas, rain, minor leaks) that does not drain off over the side of the deck.
- **Biological contamination:** when ballast water is taken up, it is bound to contain a number of microscopic life forms, such as algae and larval forms of invertebrates that belong to the specific region the ship resides in.
- **Ship accidents:** Oil spills from ships containing crude oil causes marine pollution. An accidental oil spillage can cause large damage as crude oil mainly contains different hydrocarbon molecules. Oil discharged into the sea appears as oil slicks, dissolved/dispersed petroleum hydrocarbons, floating petroleum residues (tar balls) and tar on beaches.
- **Deep Ocean Mining:** Another source of marine pollution is mining in the deep sea. An ocean mining site which drills for silver, gold, copper, cobalt and zinc create sulfide deposits up to 1400– 3700 m down in to the ocean

Types of Marine Pollution:

Marine pollution can take different forms, including:

a. **Chemical Pollution:** Chemical pollutants enter the marine environment through industrial discharges, agricultural runoff, and improper waste disposal. Examples of chemical pollutants include oil spills, heavy metals (such as mercury, lead, and cadmium), pesticides, herbicides, industrial chemicals, and pharmaceuticals. These pollutants can have toxic effects on marine organisms, leading to health issues, reproductive problems, and ecosystem disruption.

b. **Plastic Pollution:** Plastics are a major contributor to marine pollution. Discarded or improperly disposed of plastic waste enters the oceans and breaks down into smaller pieces known as microplastics. Marine animals can mistake plastic debris for food, leading to ingestion and digestive blockages. Additionally, marine animals and birds can become entangled in plastic debris, causing injuries, suffocation, or drowning.

c. **Nutrient Pollution:** Excessive nutrients, primarily from agricultural runoff, sewage discharges, and aquaculture operations, can cause nutrient pollution in marine ecosystems. The increased availability of nutrients, such as nitrogen and phosphorus, leads to excessive algal growth, known as algal blooms. These blooms can deplete oxygen levels in the water, leading to hypoxic or anoxic conditions that harm marine organisms and disrupt ecosystems.

d. **Thermal Pollution:** Thermal pollution occurs when heated water from industrial processes or power plants is discharged into the marine environment. The elevated water temperature can have detrimental effects on marine organisms, especially those sensitive to temperature changes. It can disrupt reproductive cycles, alter species distributions, and contribute to coral bleaching events.

e. **Oil Pollution:** Oil spills and leaks from offshore drilling, shipping accidents, and illegal discharges pose a significant threat to marine ecosystems. Oil spills can coat the water surface, impacting marine birds, mammals, fish, and invertebrates. The toxic components of oil can suffocate organisms, impair their ability to regulate body temperature, and contaminate habitats.

f. **Noise Pollution:** Underwater noise pollution has become a concern due to increased shipping, seismic surveys, sonar systems, and other human activities. The loud sounds can disrupt marine mammals' communication, navigation, and foraging patterns. It can cause stress, disorientation, and even physical injury to marine animals.

g. **Radioactive Pollution:** Radioactive substances can enter the marine environment through nuclear accidents or improper disposal of nuclear waste. These substances can persist in the environment for long periods and pose serious health risks to marine life and humans.

Examples of marine pollution

One of the most notable examples of marine pollution is the Deepwater Horizon oil spill that occurred in the Gulf of Mexico in 2010. An explosion on the Deepwater Horizon oil rig caused a massive release of oil into the ocean. It resulted in extensive oil slicks, contaminating marine habitats, and causing significant harm to marine life, including fish, birds, and marine mammals. Plastic pollution is a widespread issue in our oceans. Examples of plastic marine pollution include discarded plastic bags, bottles, fishing gear, and microplastics (tiny plastic particles). These items can end up in the ocean through improper waste disposal or be carried by rivers and wind. They pose a threat to marine life, as animals can ingest or become entangled in plastic debris.Industrial and chemical discharges contribute to marine pollution. For instance, untreated industrial wastewater containing toxic substances, heavy metals, and chemicals can be released directly into the ocean, contaminating the water and harming marine organisms. Agricultural runoff containing pesticides, fertilizers, and herbicides can also find its way into the ocean, leading to nutrient pollution and ecological imbalances.Improperly treated sewage and wastewater discharges from coastal cities and towns can introduce harmful pathogens, nutrients, and pollutants into the marine environment. This pollution can lead to the degradation of water quality, harm marine ecosystems, and pose risks to human health, particularly for those who come into direct contact with contaminated waters. Improper disposal or accidents related to nuclear waste can result in radioactive pollution in marine environments. Radioactive substances can contaminate seawater, affecting marine organisms and the overall ecosystem. The Fukushima nuclear disaster in Japan in 2011 released radioactive material into the Pacific Ocean, impacting marine life and posing long-term risks.Underwater noise pollution from various human activities, such as shipping, sonar systems, seismic surveys, and offshore drilling, can disrupt marine life. Marine mammals, like whales and dolphins, rely on sound for communication, navigation, and finding food. Increased levels of noise pollution can interfere with their behavior and affect their overall well-being.

Marine pollution in India

Marine pollution is a significant concern in India due to its long coastline and extensive marine resources. India's coastline, spanning over 7,500 kilometers, faces pollution challenges from both land-based and ocean-based sources. Industrial discharges, untreated sewage, agricultural runoff, and solid waste contribute to the degradation of coastal waters. The presence of industries and ports along the coast increases the risk of chemical and oil spills, impacting marine ecosystems. India has witnessed several oil spill incidents in its coastal waters. For example, the Mumbai oil spill in 2010 caused by the collision of two vessels resulted in significant pollution along the coastline, affecting marine life and habitats. Oil spills have the potential to cause long-lasting damage to marine ecosystems and pose risks to coastal communities. Plastic pollution is a growing concern in India, with the country being one of the largest contributors to marine plastic debris globally. Inadequate waste management systems, littering, and the improper disposal of plastic waste result in its entry into rivers and eventually the ocean. Major rivers like the Ganges and the Brahmaputra transport significant amounts of plastic waste into the Bay of Bengal, impacting marine life and ecosystems. Coastal cities and towns in India often face challenges in treating and managing sewage and wastewater effectively. Insufficient infrastructure and improper treatment lead to the discharge of untreated or partially treated sewage into coastal waters. This contamination can introduce pathogens, nutrients, and pollutants into marine ecosystems, posing risks to both marine life and human health. Unregulated coastal development, including infrastructure projects, ports, and tourism activities, can result in habitat destruction, coastal erosion, and disruption of marine ecosystems. The destruction of mangroves, coral reefs, and seagrass beds for development purposes has adverse effects on the health and biodiversity of marine ecosystems. Overfishing and destructive fishing practices, such as bottom trawling, dynamite fishing, and the use of illegal fishing gear, negatively impact marine biodiversity and ecosystems. These practices can lead to the depletion of fish stocks, destruction of marine habitats, and disruption of the food chain. The Government of India has recognized the importance of addressing marine pollution and has taken initiatives to mitigate its impacts. Efforts include the implementation of pollution control regulations, waste management schemes, and awareness campaigns. However, continued efforts are necessary to strengthen enforcement, improve waste management systems, and promote sustainable practices to protect India's marine environment.

Effect of marine pollution on ocean biodiversity

Marine pollution can have significant effects on ocean biodiversity. Here are some of the impacts of ocean biodiversity are such as

- **Habitat Destruction**: Pollution, such as chemical contaminants or sedimentation from runoff, can degrade or destroy important fish habitats, including coral reefs, seagrass beds, and mangrove forests. These habitats provide essential shelter, feeding grounds, and breeding areas for fish. Habitat destruction disrupts the balance of ecosystems and can lead to a decline in fish populations.

- **Contamination:** Chemical pollutants, including heavy metals, pesticides, and industrial chemicals, can accumulate in fish tissues through the process of bioaccumulation. Fish that are exposed to contaminated water can absorb and accumulate these pollutants over time. Contaminants can affect the fish's physiological functions, impair their reproductive abilities, and compromise their overall health. Consuming contaminated fish can also pose risks to human health if the pollutants bioaccumulate to levels that exceed safe limits.
- **Oxygen Depletion:** Pollution, such as nutrient runoff from agricultural activities or sewage discharges, can lead to excessive algal growth, known as algal blooms. When these blooms die and decompose, they consume oxygen from the water, leading to oxygen-depleted zones, also known as hypoxic or dead zones. Fish and other aquatic organisms rely on dissolved oxygen in the water to survive, and low oxygen levels can cause fish to suffocate or be forced to migrate to other areas, disrupting their natural behavior and migration patterns.
- **Reproductive Impairment:** Pollution can interfere with the reproductive success of fish. For instance, exposure to endocrine-disrupting chemicals (EDCs) can affect fish hormone levels and disrupt their reproductive systems. This can lead to reduced fertility, altered sex ratios, and impaired development of eggs and larvae. These effects can ultimately lead to reduced fish populations and hinder the ability of fish species to recover and maintain healthy populations.
- **Disruption of Food Chain:** Marine pollution can impact the availability and quality of food sources for fish. For example, oil spills can contaminate plankton populations, which serve as the base of the marine food chain. As a result, fish and other organisms that rely on this plankton as a food source may suffer from food scarcity or ingest toxic substances, leading to reduced growth, malnutrition, or increased susceptibility to diseases.

It is important to mitigate marine pollution and implement measures to protect fish and their habitats. This includes reducing pollutant discharges, implementing proper waste management practices, promoting sustainable fishing methods, and raising awareness about the impacts of pollution on fish and the marine environment.

5.2.2. Oil pollution

Oil pollution refers to the contamination of the environment, particularly water bodies such as oceans, seas, and rivers, by oil or petroleum products. Oil pollution can occur due to various causes, including oil spills, leaks from pipelines or storage facilities, offshore drilling accidents, and illegal discharges from ships. Here are some key points about oil pollution:Oil spills are one of the most significant contributors to oil pollution. They occur when oil is released into the environment in large quantities, typically from tanker accidents, offshore drilling mishaps, or pipeline ruptures. Oil spills can have devastating effects on marine ecosystems, wildlife, and coastal communities. The spilled oil forms slicks on the water surface, which can spread over vast areas, impacting marine life, birds, and coastal habitats. Oil pollution has severe consequences for the environment. The toxic components of oil can harm marine organisms, both directly through physical contact and indirectly through the contamination of their food sources. Oil can suffocate marine life by clogging their gills, disrupt their ability to regulate body temperature, and impair their reproductive systems. The oil can also coat and contaminate shorelines, affecting coastal ecosystems, mangroves, and wetlands. Oil spills pose a significant threat to wildlife. Birds, mammals, fish, and invertebrates can be directly affected by oil, leading to injuries, poisoning, or death. Birds' feathers can become coated in oil, impairing their ability to fly and insulate themselves from cold temperatures. Marine mammals, such as dolphins and whales, can suffer from toxic effects, respiratory problems, and damage to their habitats. The impact of oil pollution can persist long after a spill occurs. Oil can remain in the environment for years, affecting ecosystems and organisms over an extended period. It can accumulate in sediments and be ingested by bottom-dwelling organisms, entering the food chain and potentially reaching higher trophic levels, including humans. The long-term ecological effects can include population declines, reduced biodiversity, and ecosystem disruptions. Cleaning up oil spills and mitigating their impacts is challenging. Various methods and technologies are used to contain, recover, and remove spilled oil from the water surface. These methods include the use of containment booms, skimmers, sorbents, and dispersants. However, complete restoration of affected ecosystems can be difficult, and the environmental damage caused by oil pollution may persist for years or even decades. Prevention is crucial in minimizing the risk of oil pollution. This involves implementing strict regulations, conducting regular inspections and maintenance of oil infrastructure, and promoting safe practices in transportation and offshore drilling. In the event of an oil spill, a rapid and coordinated response is necessary to minimize the environmental impact. This includes containment, cleanup, and rehabilitation efforts, as well as holding responsible parties accountable. Addressing oil pollution requires a combination of preventive measures, effective response strategies, and international cooperation to protect marine ecosystems, wildlife, and coastal communities from the harmful effects of oil contamination.

Types of oil pollution

There are several types of oil pollution that can occur in the marine environment. These include

- **Oil Spills:** Oil spills are perhaps the most well-known and visible form of oil pollution. They occur when large quantities of oil are released into the environment, typically as a result of accidents, such as tanker collisions, pipeline ruptures, or offshore drilling mishaps. Oil spills can contaminate large areas of water, forming slicks on the surface.
- **Chronic Oil Pollution:** Chronic oil pollution refers to the continuous or repeated release of small amounts of oil into the environment over an extended period. It can result from ongoing activities such as industrial discharges, illegal dumping, or leakage from storage facilities or vessels. While each individual release may be relatively small, the cumulative impact can still be significant.
- **Ballast Water Contamination:** Ballast water is taken on board by ships to maintain stability and balance. However, this water often contains oil residues, sediments, and various organisms. When ballast water is discharged, it can introduce oil and other contaminants into the marine environment, leading to pollution.
- **Operational Discharges:** Operational discharges refer to the intentional or unintentional release of oil or oily waste during regular ship operations. This can include the discharge of bilge water, engine room effluents, or cleaning residues that contain oil. If not properly treated or managed, these discharges can contribute to oil pollution.
- **Oil Platform and Rig Operations:** Offshore oil platforms and drilling rigs can also contribute to oil pollution. Accidental spills or leaks during drilling, production, or transportation processes can release oil into the surrounding marine environment. These incidents can have significant environmental impacts, similar to oil spills from other sources.

Source of oil pollution

Oil pollution in the marine environment can originate from various sources. Some common sources of oil pollution are:

- **Oil Spills:** Oil spills occur when large quantities of oil are accidentally or intentionally released into the environment.
- **Shipping and Transportation:** Ships and vessels are a major source of oil pollution. Accidental spills can occur during the loading, unloading, and transportation of oil and petroleum products.
- **Offshore Oil and Gas Operations:** Offshore oil drilling and production platforms are another significant source of oil pollution
- **Industrial Discharges:** Industries that handle, process, or store oil and petroleum products can be sources of oil pollution
- **Illegal Dumping and Disposal:** Illegal dumping and improper disposal of oil-containing waste are significant sources of oil pollution.
- **Natural Seepage:** Natural oil seepage from the seafloor is another source of oil pollution, although it is relatively minor compared to human-induced sources.

Effect of marine pollution on marine diversity

Marine pollution can have significant effects on marine diversity, which refers to the variety of species and ecosystems found in the marine environment. Pollution, including chemical contaminants, oil spills, and physical debris, can degrade or destroy marine habitats such as coral reefs, seagrass beds, mangrove forests, and estuaries. Chemical pollutants, such as heavy metals, pesticides, industrial chemicals, and oil-related compounds, can enter the marine environment through various sources, including runoff, spills, and discharges. These contaminants can accumulate in the tissues of marine organisms, leading to toxic effects. Marine pollution can disrupt food chains and affect the interactions between different species. For example, oil spills or chemical contamination can contaminate plankton populations, which form the base of the marine food web. Marine pollution, along with other human activities, contributes to the decline in marine biodiversity. The loss of habitats, the introduction of invasive species, overfishing, and the destruction of ecosystems all play a role. Pollution, particularly from nutrient runoff and increased water temperatures due to climate change, can contribute to coral bleaching. Coral reefs, which are highly diverse and productive ecosystems, can bleach and eventually die when exposed to stressful conditions. Some pollutants can have genetic effects on marine organisms, including changes in gene expression, mutations, and alterations in reproductive systems of marine organism.

5.3. Water quality parameters

Water quality parameters are measurements or characteristics used to assess the physical, chemical, and biological conditions of water. These parameters provide information about the overall health and suitability of water for various uses, including drinking water, aquatic ecosystems, and recreational activities. Some important water quality parameters commonly evaluated such as:

5.3.1. Temperature:

Water temperature affects the physical and biological processes in aquatic environments. It influences the dissolved oxygen levels, metabolic rates of organisms, and overall ecosystem dynamics. Temperature measurements are typically recorded in degrees Celsius (°C) or Fahrenheit (°F).

5.3.2. pH:

pH is a measure of the acidity or alkalinity of water. The pH scale ranges from 0 (highly acidic) to 14 (highly alkaline), with 7 being neutral. Maintaining an optimal pH is essential for aquatic ecosystems and drinking water treatment processes. The pH indicates the concentration of hydrogen ions in the water. pH is an important parameter as it influences the solubility of various substances and the biological processes of aquatic organisms. The pH scale ranges from 0 to 14, with 7 being neutral. Values below 7 are acidic, and values above 7 are alkaline. Dip the pH test strip into the water sample and hold it there for a few seconds. Remove the strip and compare the color changes on the strip to the color chart provided with the test strips. The color corresponding to the closest match will indicate the pH value of the water sample.

5.3.3. Dissolved Oxygen (DO):

Dissolved oxygen is the amount of oxygen gas dissolved in water. It is essential for the survival of aquatic organisms. DO levels can vary depending on temperature, salinity, and biological activity. Insufficient dissolved oxygen can lead to hypoxia, suffocating aquatic life. DO is typically measured in milligrams per liter (mg/L) or parts per million (ppm).Dissolved oxygen analysis is a measure of the amount of oxygen dissolved in water. It is an important parameter in assessing water quality and the health of aquatic ecosystems.Obtain a representative sample of the water you want to test. Use a clean container to minimize contamination.

Winkler Method (Titration):

In this method of DO analyses add manganese (II) sulfate ($MnSO_4$) and an alkaline iodide-azide reagent (KI-$NaNO_3$) to the water sample. These reagents convert dissolved oxygen into a measurable form. After that add sulfuric acid (H_2SO_4) to the water sample. This fixes the dissolved oxygen as manganese (II) sulfate. Add sodium thiosulfate ($Na_2S_2O_3$) solution to the water sample until the brown color disappears. This titration reaction consumes the iodine that was produced during oxygen fixation. Add a few drops of starch solution to the water sample. The starch forms a deep blue color in the presence of excess iodine. Continue adding sodium thiosulfate solution drop by drop until the blue color disappears, indicating that all the iodine has reacted. The volume of sodium thiosulfate solution used in the titration corresponds to the amount of dissolved oxygen in the water sample. Calculate the concentration of dissolved oxygen using the stoichiometry of the reaction.

5.3.4. Turbidity:

Turbidity refers to the cloudiness or haziness of water caused by suspended particles, such as sediment, algae, or pollutants. High turbidity levels can reduce light penetration, affect photosynthesis, and alter the behavior and feeding patterns of aquatic organisms. Turbidity is often reported in Nephelometric Turbidity Units (NTU) or Formazin Turbidity Units (FTU).

5.3.5. Nutrients:

Nutrients, such as nitrogen and phosphorus, are essential for aquatic plant growth. However, excessive nutrient levels, often caused by agricultural runoff or wastewater discharges, can lead to eutrophication. This process promotes excessive algal growth, depletes dissolved oxygen, and harms aquatic ecosystems.

5.3.6. Biological Oxygen Demand (BOD):

BOD is a measure of the amount of dissolved oxygen consumed by microorganisms during the decomposition of organic matter in water. It indicates the level of organic pollution and the microbial activity in water. High BOD levels can deplete oxygen resources, leading to degraded water quality and harm to aquatic organisms. BOD is measured through a laboratory test called the BOD test or BOD5 test. It involves collecting a water sample in a BOD bottle, which is then sealed to prevent oxygen exchange with the atmosphere. The sealed BOD bottle is stored at a controlled temperature (usually 20°C) for a specific incubation period, typically five days (BOD5). During this time, microorganisms present in the water consume the organic matter, using oxygen for respiration. At the end of the incubation period, the dissolved oxygen concentration in the BOD bottle is measured using a dissolved oxygen probe or titration methods. This measurement represents the remaining oxygen in the water after microbial activity. The BOD value is calculated by subtracting the final dissolved oxygen concentration from the initial dissolved oxygen concentration in the water sample. This difference indicates the amount of oxygen consumed by microorganisms during the incubation period. High BOD values indicate a greater amount of organic pollutants in the water, such as sewage, industrial effluents, or excessive organic debris. High BOD levels can lead to decreased dissolved oxygen concentrations, which can negatively impact aquatic ecosystems. Insufficient dissolved oxygen can harm fish and other aquatic organisms, potentially leading to the death of sensitive species. BOD testing is crucial for monitoring and managing water quality in various settings, including wastewater treatment plants, rivers, lakes, and coastal areas. It helps assess the efficiency of wastewater treatment processes, evaluate the impact of pollution sources, and determine compliance with regulatory standards. By monitoring and controlling BOD levels, water resource managers can make informed decisions to protect and maintain the health of aquatic ecosystems and ensure the safety of water supplies for human use.

BOD (Biochemical Oxygen Demand) analysis is a measure of the amount of oxygen consumed by microorganisms while they decompose organic matter in water. It is an important parameter in assessing water quality and determining the level of organic pollution in a water sample. Clean and dry several BOD bottles (usually 300 mL) with glass stoppers. Rinse them with the water sample to be tested to minimize contamination. If the organic matter concentration in the water sample is too high, dilute it with distilled water to ensure the BOD value falls within the measurable range. Measure the dissolved oxygen (DO) concentration of the water sample immediately after collection using a dissolved oxygen meter or probe. Record the initial DO value. And add a specific volume (usually 1-2%) of a BOD seed solution to each BOD bottle. The seed solution is a mixture of wastewater or activated sludge that contains a high concentration of microorganisms. Pour a measured volume of the water sample into each BOD bottle. The volume should be sufficient to maintain a proper ratio of sample to seed solution. Prepare a control bottle by adding sterilized water (or a solution without any organic matter) and the seed solution. This serves as a reference to account for the oxygen consumption by the seed solution alone. Seal the BOD bottles tightly with the glass stoppers to prevent the exchange of atmospheric oxygen. Place the bottles in a dark location at a specific temperature (usually 20 °C). This mimics the natural conditions where microorganisms decompose organic matter. After a specific incubation period (typically 5 days), measure the DO concentration in one of the BOD bottles. This will be the final DO value. Calculate the BOD value using the following formula:

BOD = (Initial DO - Final DO) × Dilution Factor

The dilution factor is the ratio of the volume of the original water sample to the volume of the water sample added to the BOD bottle. The resulting BOD value represents the amount of oxygen consumed by microorganisms during the incubation period and provides an indication of the organic pollution in the water sample. Higher BOD values indicate a higher level of organic pollution.

5.3.7. Chemical Oxygen Demond (COD):

Chemical oxygen demand is another water quality parameter that provides information about the amount of organic and oxidizable inorganic substances present in water. COD is a measure of the oxygen required to chemically oxidize the organic matter in a water sample. COD analysis is performed in a laboratory setting. A water sample is collected and mixed with a chemical oxidizing agent, usually potassium dichromate ($K_2Cr_2O_7$). The oxidizing agent reacts with the organic matter present in the sample. The water sample and oxidizing agent mixture is heated under controlled conditions to promote the oxidation reaction. This process is often carried out using a closed reflux system or a digestion apparatus. After the oxidation reaction is complete, the remaining excess oxidizing agent is determined through titration with a reducing agent or measured using colorimetric methods. The amount of oxidizing agent consumed in the reaction is proportional to the COD of the water sample.

The COD value indicates the overall amount of organic substances present in the water, including both biodegradable and non-biodegradable compounds. High COD levels typically indicate the presence of significant organic pollution in the water, such as industrial effluents, wastewater discharges, or agricultural runoff. Organic pollutants can lead to oxygen depletion in water bodies, adversely affecting aquatic life and causing environmental degradation. COD analysis is essential for monitoring and managing water quality, particularly in industrial and wastewater treatment contexts. It helps evaluate the efficiency of treatment processes, assess the impact of pollutants, and ensure compliance with regulatory standards. By monitoring and controlling COD levels, water resource managers can take appropriate measures to protect water quality, prevent environmental degradation, and safeguard human and aquatic life.

5.3.8. Dissolved Organic Carbon (DOC):

Dissolved organic carbon is a water quality parameter that measures the concentration of organic carbon compounds present in the dissolved form in water. It includes various organic substances derived from decaying plant and animal matter, as well as synthetic organic compounds introduced through human activities. DOC is an important parameter in assessing the quality and character of natural waters, especially freshwater systems. DOC is typically measured by collecting a water sample and passing it through a filter to remove particulate matter. The filtered sample is then analyzed using a variety of laboratory techniques. Common methods include high-temperature combustion followed by infrared detection, chemical oxidation, or UV absorption spectroscopy. DOC in water bodies originates from a range of sources, including terrestrial vegetation, soil leaching, decaying organic matter, and anthropogenic inputs such as wastewater discharges and agricultural runoff. Natural processes, such as leaf litter decomposition, microbial activity, and the breakdown of organic matter, contribute to the release of organic carbon into the water. The presence of DOC can influence various aspects of water quality. It can affect the color, taste, and odor of water, contributing to the "tea-color" or brownish appearance of some natural waters. DOC can also influence the absorption and scattering of light, impacting the penetration of light into aquatic ecosystems. Furthermore, DOC serves as a substrate for microbial metabolism and can influence nutrient cycling and oxygen dynamics in water bodies. DOC plays a crucial role in the functioning of aquatic ecosystems. It provides a source of energy and nutrients for aquatic organisms, including bacteria, algae, and other microorganisms. It also influences the composition and activity of microbial communities. DOC can serve as a food source for aquatic organisms and contribute to the food web dynamics and productivity of ecosystems. Monitoring and understanding DOC levels and dynamics are essential for managing water resources and assessing ecosystem health. It provides insights into organic carbon sources, biogeochemical processes, and the overall functioning of aquatic ecosystems. Moreover, DOC analysis contributes to our understanding of carbon cycling, climate change impacts, and the role of freshwater systems in the global carbon cycle.

5.3.9. Total Dissolved Solids (TDS):

Total Dissolved Solid is a water quality parameter that measures the total concentration of inorganic salts, minerals, and other dissolved substances in water. TDS provides information about the overall mineral content and dissolved solids present in a water sample. It is an important parameter for assessing water quality and determining its suitability for various purposes. TDS is typically measured by collecting a water sample and passing it through a filter to remove any suspended particles. The filtered sample is then evaporated, and the remaining solids are weighed. The weight is expressed as milligrams per liter (mg/L) or parts per million (ppm), indicating the concentration of dissolved solids in the water. TDS includes a wide range of substances, such as salts (e.g., calcium, magnesium, sodium, and potassium), minerals (e.g., carbonates, sulfates, and chlorides), metals, organic matter, and other dissolved substances. These substances can originate from natural sources, such as weathering of rocks and soils, as well as human activities, including industrial discharges, agricultural runoff, and wastewater effluents. The sources of TDS can vary depending on the specific water body and its surrounding environment. Groundwater sources may have higher TDS concentrations due to the leaching of minerals from rocks and soils. Surface waters can receive inputs of TDS from various sources, including runoff from agricultural lands, urban areas, and industrial activities. High TDS levels can affect the taste, odor, and appearance of water. It can give water a salty or brackish taste, and in extreme cases, it may be undesirable for certain uses, such as drinking water or irrigation. Elevated TDS can also impact the suitability of water for industrial processes, aquatic habitats, and agricultural practices. While TDS itself does not pose a direct health risk, high TDS levels can indicate the presence of other contaminants, such as heavy metals or excess minerals, which may have health implications. For example, high levels of certain minerals like arsenic, lead, or fluoride can be detrimental to human health if consumed in excessive amounts. Monitoring TDS levels helps assess water quality, determine its suitability for different uses (e.g., drinking water, agriculture, industrial processes), and identify potential issues related to mineral content and dissolved solids. It is important to consider TDS levels in conjunction with other water quality parameters to obtain a comprehensive understanding of water quality characteristics.

5.3.10. Total Suspended Solids (TSS):

Total Suspended Solids (TSS) is a water quality parameter that measures the concentration of suspended particles, such as sediment, organic matter, and other solids, in water. TSS represents the total mass of solid particles that remain in suspension and can be used as an indicator of water clarity and the presence of particulate matter. TSS is typically measured by collecting a water sample and filtering it to separate the suspended particles. The filtered solids are then dried, and their weight is determined. The weight is expressed as milligrams per liter (mg/L) or parts per million (ppm), indicating the concentration of suspended solids in the water. TSS can consist of a variety of particles, including sediment, clay, silt, algae, organic matter, industrial pollutants, and other fine particles. The composition of TSS can vary depending on the water source and surrounding environment. For example, in urban areas, TSS may include road runoff, construction debris, and other urban pollutants. Suspended solids can enter water bodies through various sources, including erosion of soil and sediment from land surfaces, runoff from agricultural areas, construction activities, wastewater discharges, and natural processes such as algae blooms or resuspension of bottom sediments. Human activities can significantly contribute to the increase in TSS levels. High TSS levels can have several impacts on water quality and aquatic ecosystems. Excessive suspended solids can reduce water clarity, making the water appear turbid or cloudy. This reduction in light penetration can affect photosynthesis in aquatic plants and limit visibility for fish and other organisms. Sedimentation of TSS can also degrade aquatic habitats by smothering benthic organisms and altering substrate composition. TSS can have adverse effects on aquatic life. The deposition of sediment on fish gills can impede respiration, and the presence of high TSS levels can reduce the availability of food resources for aquatic organisms. Suspended solids can also transport nutrients, heavy metals, and other pollutants, leading to potential ecological and health risks. Monitoring TSS levels is crucial for assessing water quality, evaluating the impacts of land use activities, and identifying sources of pollution. It helps in the management and protection of aquatic ecosystems, as well as in designing appropriate erosion control and sediment management measures to mitigate the effects of suspended solids on water resources.

5.4. Control of water pollution

Water pollution at point sources can be reduced by legislation and to prevent water pollution from non-point source is difficult due to absence of proper policies and strategies. Sewage treatment is must before it released into water by physical method-sedimentation and filtration for removing large and suspended particles. Then by secondary treatment to promote bacterial treatment which leads biological oxidation carried out in oxidation pond and biosolid get formed. The tertiary treatment to pathogens, metals are removed by strong oxidizing agents like chlorine gas, ozone gas and then waste water is discharged into natural water or used for irrigation. Industrial hot water should be cooled when released from power plants or from industrial plants. Washing clothes and taking baths in tanks or wells from where supply of drinking water is made, it should be strictly prohibited.Acids and alkalis can be neutralized before releasing into water i.e., acids by lime stone and Alkalis by CO_2, sulphuric acid. Metallic salts can be precipitated before releasing. Oil spills in water, enemy of aquatic can be cleaned with Bregoli resembles saw dust. Avoid chemical fertilizers and use biofertilizers. Use of pesticides should be minimized or at least agrochemicals should be used judiciously and avoids the use along sloped area. Integral pest management need of sustainable yield. Use nitrogen fixing plants as supplements to the fertilizers. Separate drainage channels for sewage and rain water should be provided. Nutrient rich water should not be used as fertilizer in field. Water pollution can be controlled and minimized by ecosystem stability. Activated carbon absorbents reduce the level of pollutants when waste water passes through and technique is used to remove pesticides/insecticides

5.5. Summary

Water pollution is a significant environmental issue that occurs when harmful substances enter water bodies and degrade their quality. It poses a threat to ecosystems, human health, and the overall balance of our planet's natural systems. This summary provides an overview of water pollution, its causes, effects, and potential solutions. Water pollution can be attributed to various sources, including industrial activities, agricultural practices, municipal wastewater, improper disposal of waste, oil spills, and urban runoff. Industrial processes release toxic chemicals and heavy metals into water bodies, while agricultural runoff carries fertilizers, pesticides, and animal waste. Improper sewage treatment and inadequate wastewater management contribute to the contamination of water sources. Additionally, oil spills from shipping and offshore drilling activities result in devastating pollution incidents. The effects of water pollution are far-reaching and impact both ecosystems and human beings. Aquatic ecosystems suffer from the loss of biodiversity, as pollutants disrupt the delicate balance of marine and freshwater ecosystems. Contaminants in the water can harm aquatic plants and animals, leading to reduced populations and impaired reproductive capabilities. Furthermore, water pollution can result in the eutrophication of water bodies, causing excessive algal growth, oxygen depletion, and the creation of dead zones where aquatic life cannot survive. Human health is also significantly affected by water pollution. Contaminated water can transmit diseases such as cholera, typhoid, and hepatitis, leading to illness and even death. Pollutants in water sources can accumulate in the food chain, potentially causing long-term health issues for those who consume contaminated fish and shellfish. Moreover, exposure to polluted water for recreational activities like swimming and bathing can lead to skin rashes, respiratory problems, and gastrointestinal disorders. Water pollution is a pressing environmental challenge with severe consequences for ecosystems and human well-being. By implementing pollution prevention measures, improving wastewater treatment, enforcing regulations, raising public awareness, promoting sustainable practices, and fostering international cooperation, we can mitigate water pollution and ensure the availability of clean and safe water for current and future generations.

5.6. Terminal questions

Q.1. What is water pollution? Discuss the sources and effects of water pollution.

Answer:--

Q.2. Define the marine pollution, its sources and effects on ocean diversity.

Answer:---

Q.3. What is the oil pollution? Write the types of oil pollution.

Answer:---

Q.4. What is water quality parameter? Discuss the Chemical oxygen demand (COD) and its analysis.

Answer:---

Q.5. Write the difference dissolved oxygen and biochemical oxygen demand (BOD).

Answer:---

Q.6. What is the total suspended solid? Discuss the suspended solid and its permissible limits in drinking water.

Answer:---

5.7. Further suggested readings

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6. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.

7. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd.

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Unit-6: Wastewater and Industrial Effluents

Contents

6.1. Introduction

Wastewater and industrial effluent are terms used to describe the water that has been contaminated through various human activities and is no longer suitable for immediate use. These terms refer to the liquid waste generated from residential, commercial, and industrial sources, which contains a wide range of pollutants and contaminants. Managing and treating wastewater and industrial effluent is essential for maintaining public health, protecting the environment, and ensuring sustainable water resources. Wastewater originates from numerous everyday activities, such as domestic water use, sanitation, and urban runoff. It contains a mixture of organic and inorganic substances, including human waste, soaps, detergents, food scraps, chemicals, and heavy metals. On the other hand, industrial effluent refers specifically to the wastewater generated by industrial processes. This effluent can be highly contaminated, as it may contain chemicals, heavy metals, oils, solvents, and other pollutants specific to the industry. The discharge of untreated or inadequately treated wastewater and industrial effluent into water bodies can have severe consequences. It can contaminate drinking water sources, harm aquatic ecosystems, and pose risks to human health. Pathogens present in wastewater can cause waterborne diseases such as cholera, typhoid, and hepatitis. Additionally, the high levels of nutrients like nitrogen and phosphorus in wastewater can lead to eutrophication, a process that depletes oxygen in water bodies and harms fish and other aquatic life. To mitigate these risks, wastewater and industrial effluent are treated through a series of processes. The primary treatment involves the physical removal of large solids through screening and settling processes. After primary treatment, secondary treatment takes place, where biological processes, such as activated sludge or trickling filters, are used to break down organic matter and remove nutrients. Finally, in some cases, tertiary treatment is employed to further remove specific contaminants, such as pathogens, heavy metals, or pharmaceutical residues. Wastewater and industrial effluent pose significant challenges to the environment and public health. Proper management and treatment of these waste streams are essential to protect water resources and ecosystems. Through the implementation of effective treatment processes, the reuse of treated effluent, and the enforcement of regulations, we can minimize the impact of wastewater and industrial effluent and move towards a more sustainable and environmentally responsible approach to water management.

Objectives

- To discuss the wastewater and its characteristics
- To discuss the nature of wastewater and its treatment
- To discuss the waste water pathogenic bacteria and waste water born diseases
- To discuss the nature and chemical composition of activated sludge and its treatment
- To discuss the advanced oxidation process for wastewater treatment

6.2. Waste water

Wastewater is a term used to describe water that has been used in various human activities, such as domestic, commercial, and industrial activities, and is no longer suitable for immediate use. It contains a mixture of organic and inorganic substances, including human waste, soaps, detergents, food scraps, chemicals, and heavy metals. Wastewater can be categorized into two types: domestic wastewater and industrial wastewater. Domestic wastewater is generated from residential sources, such as homes, apartments, and public facilities like schools and hospitals. It typically contains organic matter, nutrients, and pathogens from human waste and cleaning products. Industrial wastewater, on the other hand, is generated by various industries and manufacturing processes and contains a range of chemicals and pollutants specific to the industry. Managing and treating wastewater is essential for maintaining public health, protecting the environment, and ensuring sustainable water resources. The discharge of untreated or inadequately treated wastewater into water bodies can contaminate drinking water sources, harm aquatic ecosystems, and pose risks to human health. Pathogens present in wastewater can cause waterborne diseases such as cholera, typhoid, and hepatitis. The high levels of nutrients like nitrogen and phosphorus in wastewater can lead to eutrophication, a process that depletes oxygen in water bodies and harms fish and other aquatic life. Efforts are also being made to promote the concept of "water reuse" in managing wastewater. Water reuse involves the treatment and repurposing of wastewater for various non-potable purposes, such as irrigation, industrial uses, or toilet flushing. This approach not only conserves water resources but also reduces the environmental impact associated with wastewater generation. Wastewater management is a critical aspect of ensuring public health, protecting the environment, and maintaining sustainable water resources. Through the implementation of effective treatment processes, the reuse of treated wastewater, and the enforcement of regulations, we can minimize the impact of wastewater and move towards a more sustainable and environmentally responsible approach to water management.

6.3. Industrial effluent

Industrial effluent refers to the wastewater generated by industrial processes. It contains a wide range of pollutants and contaminants that are specific to the industry producing it. Industrial effluent can be highly contaminated, as it may contain chemicals, heavy metals, oils, solvents, and other substances used or produced during industrial operations. The composition of industrial effluent varies depending on the type of industry. For example, effluent from chemical manufacturing plants may contain hazardous chemicals and organic compounds, while effluent from metal processing industries may contain high concentrations of heavy metals. Other industries, such as textile manufacturing, food processing, and pharmaceutical production, also generate effluent with their specific pollutants. Managing and treating industrial effluent is essential to protect the environment, public health, and water resources. If released untreated or inadequately treated, industrial effluent can have severe impacts on ecosystems and human health. It can contaminate water bodies, leading to the destruction of aquatic life and the degradation of ecosystems. Moreover, the presence of toxic substances in industrial effluent can pose health risks to people living near industrial areas or using water sources affected by the discharge. Chemical precipitation involves the addition of chemicals that react with the contaminants in the effluent to form solid precipitates that can be easily separated. Ion exchange is used to remove heavy metals and other ions from the effluent by exchanging them with less harmful ions in a resin bed. Sedimentation and filtration processes are employed to separate solids and suspended particles from the effluent. Biological treatment methods utilize microorganisms to break down organic matter and remove pollutants through processes like activated sludge, aerobic or anaerobic digestion, and constructed wetlands. Industrial effluent poses significant challenges to the environment and human health due to its diverse range of pollutants. Proper management, treatment, and regulation are essential to minimize its impact. Through the adoption of treatment technologies, pollution prevention strategies, and regulatory frameworks, industrial effluent can be effectively managed, protecting water resources and promoting sustainable industrial practices.

6.3.1. Source of industrial effluent:

Industrial effluent can originate from various sectors and industries. The specific sources of industrial effluent can vary depending on the region, local industries, and the specific processes employed within each industry. Additionally, the composition and volume of effluent can vary widely depending on the industry and the effectiveness of treatment measures in place. Some common sources of industrial effluent are followings:

- **Manufacturing industries:** Effluent is generated from manufacturing processes such as chemical production, textile manufacturing, pulp and paper mills, metal processing, electronics manufacturing, and pharmaceutical production.

- **Food and beverage industry:** Effluent is produced from food processing plants, breweries, distilleries, dairies, and slaughterhouses.
- **Mining and mineral processing:** Effluent is generated from mining operations, mineral processing plants, and coal mines.
- **Oil and gas industry:** Effluent is produced from oil refineries, petrochemical plants, offshore drilling operations, and gas processing facilities.
- **Power generation:** Effluent can be generated from thermal power plants, nuclear power plants, and hydropower facilities.
- **Chemical industry:** Effluent is produced from chemical manufacturing plants, including those involved in the production of fertilizers, pesticides, plastics, and specialty chemicals.
- **Textile industry:** Effluent is generated from textile dyeing and finishing operations, which often involve the use of various chemicals and dyes.
- **Automotive industry:** Effluent can be produced from car manufacturing plants, where processes such as painting, metalworking, and cleaning generate wastewater.
- **Construction industry:** Effluent may come from construction sites, where activities like concrete production, excavation, and demolition can produce contaminated water runoff.
- **Pharmaceutical industry:** Effluent is generated from pharmaceutical manufacturing facilities, which produce wastewater containing active pharmaceutical ingredients and other chemicals.

6.4. Composition of industrial effluent

The composition of industrial effluent can vary widely depending on the type of industry and the specific processes involved. Different industries produce effluent with unique characteristics and pollutants. The specific composition of industrial effluent can vary significantly depending on factors such as the type of industry, the specific processes and chemicals used, and the effectiveness of any treatment measures in place. As a result, the treatment and management of industrial effluent require tailored approaches to address the unique challenges and characteristics associated with each industry. However, some common components found in industrial effluent include:

Chemicals: Various industries use and generate a wide range of chemicals that can be present in effluent. These chemicals may include solvents, acids, alkalis, detergents, pesticides, and synthetic compounds.

Heavy metals: Industries such as mining, metal processing, and electroplating can release effluent containing heavy metals such as lead, mercury, cadmium, chromium, and arsenic. These metals are often highly toxic and can have significant environmental and health impacts.

Organic compounds: Many industrial processes involve the use of organic substances that can end up in effluent. These can include oils, greases, fuels, hydrocarbons, and volatile organic compounds (VOCs). Organic compounds can have harmful effects on aquatic life and may be persistent in the environment.

Suspended solids: Effluent from industries often contains solid particles, such as sediments, particulate matter, and insoluble materials. These solids can contribute to water turbidity and affect aquatic ecosystems by blocking sunlight penetration and reducing oxygen levels.

Nutrients: Certain industries, including food processing and agricultural operations, may release effluent rich in nutrients such as nitrogen and phosphorus. While these nutrients are essential for plant growth, excessive amounts in water bodies can lead to eutrophication, causing harmful algal blooms and oxygen depletion.

pH imbalance: Industrial processes can alter the pH of effluent, resulting in acidic or alkaline conditions. Extreme pH levels can be harmful to aquatic organisms and affect water quality.

Temperature: Some industries discharge effluent at elevated temperatures due to their manufacturing or cooling processes. Thermal pollution can adversely impact aquatic ecosystems and disrupt the natural balance of temperature-sensitive organisms.

6.5. Sludge

Sludge is a semi-solid or solid residual material that is generated during the treatment of wastewater, industrial effluent, or other types of water treatment processes. It consists of a combination of water, organic matter, inorganic substances, and microorganisms. The characteristics of sludge can vary depending on the source, treatment process, and specific composition, but some common characteristics include:

Moisture content: Sludge typically contains a significant amount of water, with moisture content ranging from 60% to 99%. The moisture content affects the handling, transportation, and further processing of sludge.

Organic matter: Sludge contains organic compounds derived from the wastewater or industrial effluent being treated. These organic materials can include biodegradable substances such as sewage, food waste, and organic chemicals. The organic matter content of sludge contributes to its potential for energy recovery through processes like anaerobic digestion.

Inorganic substances: Sludge may also contain inorganic substances such as sand, grit, metals, and inert materials. These substances are often removed during the wastewater treatment process but can still be present in the sludge to some extent.

Nutrient content: Sludge can contain significant amounts of nutrients, including nitrogen, phosphorus, and potassium. These nutrients, which originate from wastewater or industrial sources, can be beneficial for agricultural use or may require further treatment to meet specific disposal requirements.

Microorganisms: Sludge contains a diverse population of microorganisms, including bacteria, fungi, viruses, and protozoa. These microorganisms play a crucial role in the biological treatment processes and contribute to the decomposition and stabilization of organic matter in the sludge.

Pathogens: Sludge can also harbor various pathogens, including bacteria, viruses, and parasites. These pathogens may originate from the wastewater source and can pose risks to human health if not properly treated or handled.

Volume and density: The volume and density of sludge can vary depending on its composition and moisture content. Sludge can range from being relatively thick and dense to more fluid and liquid-like, depending on the treatment process and the desired consistency for handling and disposal.

It's important to note that the characteristics of sludge can be modified through various treatment processes. Treatment methods such as dewatering, stabilization, digestion, and drying can reduce moisture content, stabilize organic matter, and reduce pathogen levels, making the sludge more manageable for further use or disposal.

6.6. Activated sludge

Activated sludge is a widely used wastewater treatment process that involves the use of microorganisms to break down organic matter in wastewater. It is a biological treatment method that utilizes a combination of aerobic bacteria, protozoa, and other microorganisms to remove pollutants and improve the quality of the treated water.The activated sludge process typically consists of the following components:

- **Aeration tank:** This is the main component of the activated sludge system, where wastewater and a mixed culture of microorganisms, known as activated sludge, are combined. The aeration tank is equipped with diffusers or mechanical aerators that introduce air or oxygen into the wastewater, creating an aerobic environment that supports the growth and activity of microorganisms.
- **Return activated sludge (RAS):** A portion of the settled sludge from the secondary clarifier is recycled back to the aeration tank. This return activated sludge helps maintain a sufficient population of microorganisms and provides biomass for the treatment process.
- **Mixed liquor suspended solids (MLSS):** MLSS refers to the concentration of suspended solids, including microorganisms, in the aeration tank. It is an important parameter that is closely monitored and controlled to ensure optimal treatment performance.
- **Secondary clarifier:** After the wastewater has been treated in the aeration tank, it flows into the secondary clarifier. In this settling tank, the activated sludge particles settle to the bottom as sludge, while the clarified water, known as effluent, is discharged or further treated as needed.

The activated sludge process works through a series of biological reactions carried out by the microorganisms in the aeration tank. The microorganisms utilize the organic matter present in the wastewater as a food source and convert it into carbon dioxide, water, and biomass. This process is known as the aerobic degradation of organic matter.The efficiency of the activated sludge process depends on several factors, including the retention time in the aeration tank, the ratio of wastewater flow to activated sludge biomass (known as the sludge age), dissolved oxygen concentration, and nutrient availability (such as nitrogen and phosphorus). The treated effluent from the activated sludge process is typically of significantly improved quality compared to the influent wastewater. However, further treatment processes may be employed, such as tertiary treatment, to meet specific water quality standards or to remove additional contaminants.

Overall, activated sludge is a widely adopted and effective biological wastewater treatment process that helps to remove organic pollutants and improve the quality of wastewater before its discharge into the environment.

6.6.1. Composition of activated sludge

Activated sludge is a complex mixture of microorganisms, organic matter, inorganic particles, and water. The composition of activated sludge can vary depending on several factors, including the characteristics of the wastewater being treated, the operational parameters of the treatment plant, and the specific microorganisms present. The components typically found in activated sludge are followings:

Microorganisms: The activated sludge consists of a diverse community of microorganisms, including bacteria, fungi, protozoa, and sometimes rotifers and nematodes. These microorganisms play a crucial role in the treatment process by metabolizing and degrading organic matter present in the wastewater.

Organic matter: Activated sludge contains organic compounds that are derived from the wastewater being treated. This includes biodegradable substances such as carbohydrates, proteins, fats, oils, and other organic compounds. The organic matter serves as a food source for the microorganisms, and their metabolic activities result in the breakdown and conversion of organic pollutants.

Inorganic particles: Activated sludge can contain various inorganic particles and suspended solids that are present in the wastewater. These particles may include sand, grit, clay, minerals, and other non-biodegradable substances. Inorganic particles can affect the settling characteristics of the sludge and may require removal or management during the treatment process.

Water: Activated sludge is primarily composed of water, which makes up the majority of its volume. The water in the sludge originates from the wastewater being treated and can contain dissolved substances and ions.

Extracellular polymeric substances (EPS): EPS are complex compounds secreted by the microorganisms in the activated sludge. EPS play a vital role in the formation and structure of the sludge flocs, providing cohesion and stability. EPS also contribute to the settling characteristics of the sludge and facilitate the removal of solids during the settling process.

Nutrients: Activated sludge may contain various nutrients required for microbial growth and metabolic processes. These nutrients include nitrogen (in the form of ammonia, nitrite, and nitrate) and phosphorus. The availability and concentration of nutrients in the activated sludge can influence the treatment efficiency and the growth of microorganisms.

It's important to note that the composition of activated sludge is dynamic and can change over time due to fluctuations in wastewater characteristics, process conditions, and the presence of different microbial species. Regular monitoring and control of the treatment process, including maintaining optimal sludge age, nutrient balance, and environmental conditions, are necessary to ensure efficient and effective treatment performance.

6.7. Eutrophication

Eutrophication is a process that occurs when a water body, such as a lake, river, or coastal area, becomes enriched with excessive nutrients, primarily nitrogen and phosphorus. This nutrient enrichment leads to an accelerated growth of algae and other aquatic plants, a phenomenon known as algal bloom. Eutrophication is a significant environmental issue with numerous ecological and economic implications. The process of eutrophication typically involves the following steps:

- **Excessive Nutrient Input:** The primary cause of eutrophication is the input of excessive nutrients into the water body. This can result from various human activities, such as agricultural runoff, sewage discharges, industrial effluents, and the use of fertilizers. These nutrients are often carried by surface runoff or through groundwater into nearby water bodies.

- **Algal Blooms:** The elevated nutrient levels promote the growth of algae and other aquatic plants in the water body. Algal blooms can occur rapidly, leading to dense populations of algae covering the water surface. These blooms can be green, blue-green, red, or brown in color and may produce toxins harmful to aquatic organisms and humans.
- **Decreased Water Clarity:** As the algal blooms proliferate, they can reduce water clarity by blocking sunlight from reaching deeper water layers. This reduction in light penetration negatively impacts submerged aquatic plants, which depend on sunlight for photosynthesis. Reduced water clarity also affects the visual appeal of the water body and can limit recreational activities such as swimming and fishing.
- **Oxygen Depletion:** Algal blooms eventually die and decompose. During decomposition, bacteria and other microorganisms consume oxygen, leading to oxygen depletion in the water. This depletion is particularly severe during the night when photosynthesis ceases, and respiration continues. Oxygen-depleted conditions, known as hypoxia or anoxia, can harm fish, shellfish, and other aquatic organisms, resulting in fish kills and the collapse of ecosystems.
- **Changes in Aquatic Community:** Eutrophication can cause shifts in the composition of the aquatic community. Algal blooms may outcompete native aquatic plants, leading to a decrease in plant diversity. Additionally, the oxygen depletion and release of toxins during the decomposition process can be harmful to fish, invertebrates, and other organisms. This can result in declines or shifts in fish populations and disruptions to the food chain.
- **Economic and Social Impacts:** Eutrophication can have significant economic consequences. It can impair recreational activities, such as swimming, boating, and fishing, leading to economic losses for tourism-dependent areas. The decline in water quality can also impact industries relying on clean water, such as aquaculture and water supply. Furthermore, the cost of treating drinking water to remove excessive nutrients can be substantial.

Preventing and mitigating eutrophication involves implementing measures to reduce nutrient inputs into water bodies. This includes better agricultural practices, proper wastewater treatment, and responsible fertilizer use. Additionally, restoration efforts such as nutrient removal techniques, artificial aeration, and the use of buffer zones can help improve water quality in eutrophic systems. Addressing eutrophication requires a comprehensive and collaborative approach involving governments, industries, communities, and individuals to protect and restore the health of water bodies and ensure sustainable management of water resources.

6.7.1. Types of eutrophication

Here are two main types of eutrophication: natural eutrophication and cultural (or anthropogenic) eutrophication. While both types involve the excessive enrichment of nutrients in water bodies, their causes and characteristics differ.

- **Natural Eutrophication:**

Natural eutrophication occurs over long periods of time, typically spanning centuries or even millennia. It is a natural process that happens as water body's age and gradually accumulates nutrients. Over time, sediments and organic matter build up, and nutrients such as nitrogen and phosphorus are released into the water. This slow and natural process of eutrophication is part of the aging process of lakes and ponds. It is generally a slow and balanced process that allows the aquatic ecosystem to adapt and maintain a certain level of equilibrium.

- **Cultural (Anthropogenic) Eutrophication:**

Cultural eutrophication is a result of human activities and occurs at a much faster rate than natural eutrophication. It is primarily caused by human inputs of nutrients, particularly nitrogen and phosphorus, into water bodies. The main sources of nutrient pollution include agricultural runoff, sewage discharges, industrial effluents, and the use of fertilizers. These activities increase the nutrient load in water bodies, leading to accelerated growth of algae and other aquatic plants, resulting in algal blooms and subsequent ecological changes. Cultural eutrophication is a significant environmental issue and is often associated with human population growth, urbanization, and industrialization.

6.7.2. Impact of eutrophication

Eutrophication has significant impacts on ecology and the environment, affecting various components of aquatic ecosystems. Here are some key impacts of eutrophication:

- **Algal Blooms:** Excessive nutrient enrichment promotes the growth of algae and cyanobacteria, leading to the formation of algal blooms. These blooms can cover the water surface and reduce sunlight penetration, inhibiting the growth of submerged aquatic plants.

The dominance of certain algae species can disrupt the natural balance of the ecosystem and decrease overall biodiversity.

- **Oxygen Depletion:** Algal blooms eventually die and decompose. During decomposition, microorganisms consume oxygen, leading to oxygen depletion in the water. This process is known as oxygen sag, and it can create hypoxic (low oxygen) or anoxic (no oxygen) conditions in the water, which are harmful to fish and other aquatic organisms. Oxygen depletion can result in fish kills, disruptions to the food chain, and the loss of sensitive species.
- **Loss of Habitat and Biodiversity:** Eutrophication can lead to the loss of aquatic plant species, including submerged macrophytes. These plants provide essential habitats, spawning grounds, and nurseries for many aquatic organisms. Their decline can result in the loss of biodiversity, as well as changes in the composition and abundance of fish and invertebrate populations.
- **Harmful Algal Blooms (HABs):** Some species of algae, particularly cyanobacteria, can produce toxins during algal blooms. These toxins, known as harmful algal blooms (HABs) or cyanobacterial harmful algal blooms (CHABs), can pose serious risks to aquatic organisms, wildlife, and human health. HABs can cause fish kills, contaminate drinking water sources, and result in illnesses or even fatalities in humans and animals that come into contact with or consume the affected water.
- **Disruption of Food Web:** Eutrophication can alter the structure and functioning of the aquatic food web. Algal blooms can provide a temporary surge in food availability, leading to increased populations of herbivorous zooplankton and other organisms that feed on algae. However, the subsequent decomposition of the algae and oxygen depletion can cause a collapse in populations of fish, invertebrates, and other higher trophic level organisms that rely on oxygen-rich water.
- **Water Quality Issues:** Eutrophication often leads to degraded water quality in affected water bodies. The excessive growth of algae and the accumulation of organic matter can result in murky, turbid water with reduced clarity. This can impact the aesthetics of the water body and limit recreational activities such as swimming, boating, and fishing. Additionally, eutrophication can lead to foul odors and taste issues in drinking water supplies.

- **Economic Implications:** The environmental impacts of eutrophication have significant economic consequences. The decline in water quality can harm industries dependent on clean water, such as fisheries, aquaculture, and tourism. The costs associated with treating drinking water to remove excess nutrients, managing algal blooms, and restoring affected ecosystems can also be substantial.

To mitigate the impacts of eutrophication, efforts are focused on reducing nutrient inputs into water bodies, implementing effective wastewater treatment, adopting sustainable agricultural practices, and promoting responsible nutrient management. Restoring affected ecosystems through measures such as nutrient removal techniques, wetland restoration, and the establishment of buffer zones can also help to mitigate the impacts of eutrophication and restore ecological balance.

6.8. Algal bloom

Algal blooms occur when there is a rapid and excessive growth of algae in aquatic ecosystems. These blooms can have various ecological and environmental impacts.

Red Tide (Harmful Algal Bloom):

Red tide is a type of harmful algal bloom caused by the rapid proliferation of certain species of dinoflagellates, such as Karenia brevis. These blooms often occur in coastal areas and produce toxins known as brevetoxins. Red tide can lead to the discoloration of water, giving it a reddish or brownish hue, and can result in fish kills and the deaths of marine mammals and birds. The toxins produced by red tide can also cause respiratory issues and shellfish poisoning in humans if contaminated shellfish are consumed.

- **Cyanobacterial Harmful Algal Blooms (CHABs):**

Cyanobacterial blooms are caused by the rapid growth of certain species of cyanobacteria, also known as blue-green algae. These blooms are often found in freshwater bodies such as lakes, ponds, and rivers. Cyanobacterial blooms can produce toxins called cyanotoxins, which can be harmful to aquatic organisms, livestock, wildlife, and humans. They can cause skin irritations, gastrointestinal issues, and liver damage if exposed or ingested.

- **Green Algal Blooms:**

Green algal blooms are caused by the excessive growth of green algae, such as species from the genus Chlorella and Spirogyra. These blooms are often observed in nutrient-rich freshwater bodies and can result in the water appearing green or murky. While not necessarily harmful, green algal blooms can still have negative impacts on aquatic ecosystems. They can deplete oxygen levels, leading to fish kills, and create unfavorable conditions for other organisms, including submerged aquatic plants.

- **Diatom Blooms:**

Diatoms are a type of single-celled algae that are widespread in both freshwater and marine environments. Diatom blooms occur when certain diatom species experience rapid growth and become dominant in the water column. These blooms can cause water discoloration, ranging from brown to yellow-green. Diatom blooms play an essential role in the food chain by providing food for zooplankton and other organisms. However, under certain conditions, they can contribute to oxygen depletion and subsequent negative impacts on fish and other aquatic life.

6.8.1. Measureof eutrophication

Eutrophication can be measured using various indicators and monitoring techniques. Some common methods used to measure and assess eutrophication:

- **Nutrient Concentrations:** Monitoring the concentration of key nutrients, such as nitrogen and phosphorus, is crucial in assessing eutrophication. Water samples are collected from different points in a water body and analyzed in a laboratory for nutrient levels. High nutrient concentrations indicate a greater risk of eutrophication.
- **Chlorophyll-a Concentrations:** Chlorophyll-a is a pigment found in algae and serves as an indicator of algal biomass in the water. Monitoring chlorophyll-concentrations provides insights into the extent of algal growth and the potential for algal blooms. Water samples are collected and analyzed to quantify the chlorophyll-a concentration.
- **Secchi Disk Depth:** Secchi disk depth is a measure of water transparency or clarity. A Secchi disk is a white or black and white disk that is lowered into the water until it is no longer visible. The depth at which it disappears provides an indication of water transparency. A decrease in Secchi disk depth suggests reduced water clarity, which is often associated with eutrophication.

- **Dissolved Oxygen Levels:** Dissolved oxygen is a critical parameter in assessing the health of aquatic ecosystems. Eutrophication can lead to oxygen depletion as a result of algal blooms and subsequent decomposition. Monitoring dissolved oxygen levels helps determine if hypoxic (low oxygen) or anoxic (no oxygen) conditions are present, which can be harmful to fish and other aquatic organisms.
- **Biological Assessments:** Biological assessments involve studying the abundance and diversity of aquatic organisms to evaluate eutrophication impacts. This can include measuring the abundance of algae, aquatic plants, zooplankton, fish, and macroinvertebrates. Changes in species composition and population dynamics can provide insights into the ecological effects of eutrophication.
- **Remote Sensing:** Remote sensing techniques use satellite imagery and aerial photography to monitor eutrophication on a larger scale. This method allows for the assessment of algal blooms, water color, and vegetation dynamics over a wide area. Remote sensing data can provide valuable information on the spatial and temporal patterns of eutrophication.

It is important to note that measuring eutrophication is often a multidimensional process, as eutrophication impacts various aspects of aquatic ecosystems. Combining multiple indicators and monitoring methods provides a more comprehensive understanding of the eutrophication status and allows for better management and mitigation strategies to be implemented.

6.8.2. How to control eutrophication

To control eutrophication, several measures can be implemented. Here are some key strategies in bullet point format:

- Implement nutrient management practices in agriculture, such as:
  - Applying fertilizers based on soil nutrient testing and crop requirements.
  - Using slow-release or controlled-release fertilizers to minimize nutrient runoff.
  - Employing conservation practices like cover cropping, crop rotation, and buffer strips to reduce nutrient losses from fields.
- Implement proper wastewater treatment:
  - Upgrade wastewater treatment plants to include nutrient removal technologies
  - Implement advanced treatment methods, such as tertiary treatment or nutrient stripping, to reduce nutrient loads in discharged water.

  - Encourage the use of decentralized treatment systems, such as constructed wetlands or biofilters, to treat smaller-scale wastewater sources.
- Control and manage storm water runoff:
  - Implement best management practices to capture and treat stormwater runoff before it enters water bodies.
  - Incorporate green infrastructure techniques, such as rain gardens, permeable pavement, and constructed wetlands, to promote natural filtration and nutrient uptake.
- Control the use of phosphorus-containing detergents and cleaning products:
  - Promote the use of phosphate-free or low-phosphate alternatives in household cleaning products.
  - Enforce regulations on phosphorus content in commercial cleaning products
  - Establish and enforce buffer zones and riparian vegetation:
  - Protect and restore riparian areas and establish buffer zones along water bodies to trap and filter nutrients before they enter the water.
  - Plant native vegetation that can absorb excess nutrients and stabilize the soil, preventing nutrient runoff.
- Implement lake and reservoir management strategies:
  - Implement aeration or oxygenation techniques to prevent oxygen depletion.
  - Control algae growth through the use of algaecides or algal control measures.
  - Apply nutrient inactivation methods, such as chemical precipitation or biological nutrient removal, to reduce nutrient concentrations.
- Raise public awareness and education:
  - Educate the public about the impacts of eutrophication and the role of individual actions in nutrient reduction.
  - Promote responsible fertilizer use, proper disposal of household chemicals, and water conservation practices.
- Enhance monitoring and research:
  - Conduct regular monitoring of water bodies to assess nutrient levels, algal growth, and ecosystem health.
  - Invest in research and innovation to develop new technologies and strategies for eutrophication control and nutrient management.

- It's important to note that eutrophication control requires a holistic and integrated approach involving multiple stakeholders, including government agencies, industries, farmers, and the general public. Collaboration and long-term commitment are essential for effectively managing and mitigating eutrophication.

6.9. Role of soaps, detergent and phosphorus fertilizer in eutrophication

Soaps, detergents, and phosphorus fertilizers can contribute to eutrophication by introducing excessive amounts of phosphorus into water bodies. Phosphorus is a key nutrient that promotes the growth of algae and aquatic plants. Here's a breakdown of how these substances can impact eutrophication:

- **Soaps and Detergents:**

Many household cleaning products, including soaps and detergents, contain phosphates as a key ingredient. When these products are used for cleaning or washing activities, phosphates can be washed down drains and enter wastewater systems. If the wastewater is not adequately treated, phosphates can be discharged into rivers, lakes, or other water bodies.Once in the water, phosphates act as a fertilizer, promoting the growth of algae and aquatic plants. This excessive growth can lead to algal blooms, reduced water clarity, and oxygen depletion. Additionally, the decomposition of the algae can further deplete oxygen levels in the water, negatively impacting fish and other aquatic organisms. To mitigate the impact of soaps and detergents on eutrophication, many countries have implemented regulations and encouraged the use of phosphate-free or low-phosphate cleaning products. These products reduce the amount of phosphorus entering wastewater and help mitigate eutrophication.

- **Phosphorus Fertilizers:**

Phosphorus is an essential nutrient for plant growth, and it is commonly used in the form of phosphorus-based fertilizers in agriculture. When phosphorus fertilizers are applied to farmland, excess phosphorus can be washed away by rainfall or irrigation water, eventually finding its way into nearby water bodies through surface runoff or leaching into groundwater. The introduction of excess phosphorus from fertilizers into water bodies can lead to eutrophication. The additional phosphorus acts as a nutrient source for algae and aquatic plants, causing excessive growth and algal blooms. The subsequent decomposition of the algal biomass consumes oxygen, leading to oxygen depletion and potentially harming fish and other aquatic organisms. To minimize the impact of phosphorus fertilizers on eutrophication, agricultural best management practices are crucial. These practices aim to optimize fertilizer application rates, timing, and methods to minimize nutrient runoff and leaching. Additionally, implementing conservation practices such as buffer strips, cover crops, and nutrient management plans can help reduce phosphorus losses from agricultural fields. Overall, the use of soaps, detergents, and phosphorus fertilizers can contribute to eutrophication by introducing excess phosphorus into water bodies. Proper wastewater treatment, phosphate-free or low-phosphate cleaning products, and responsible nutrient management in agriculture are essential to mitigate these impacts and protect water quality.

6.10. Pathogenic bacteria in wastewater

Wastewater can contain various pathogenic bacteria, which are microorganisms capable of causing diseases in humans and animals. Here are some examples of pathogenic bacteria commonly found in wastewater:

- **Escherichia coli (E. coli):** E. coli is a common bacterium found in the intestines of humans and animals. While most strains of E. coli are harmless, some can cause serious illnesses such as diarrhea, urinary tract infections, and even life-threatening conditions like hemolytic uremic syndrome (HUS). Contamination of wastewater with fecal matter can introduce pathogenic strains of E. coli into the water.
- **Salmonella spp.:** Salmonella is a group of bacteria known to cause salmonellosis, a food borne illness. It can be present in the gastrointestinal tracts of animals and humans and is typically transmitted through contaminated food and water. Wastewater contaminated with fecal matter can contain Salmonella bacteria, posing a risk of infection if not properly treated.
- **Campylobacter spp.:** Campylobacter is a leading cause of bacterial gastroenteritis worldwide. It is commonly associated with the consumption of contaminated food, but wastewater can also be a potential source of Campylobacter infection. Proper wastewater treatment is necessary to prevent the spread of this pathogen.
- **Shigella spp.:** Shigella bacteria are responsible for causing shigellosis, a diarrheal disease. The bacterium is highly contagious and can spread through fecal-oral transmission, making

contaminated wastewater a potential source of infection. Proper sanitation and wastewater treatment are essential to prevent the transmission of Shigella.

- **Vibrio cholerae:** Vibrio cholerae is the bacterium responsible for cholera, a severe diarrheal disease. Although cholera is primarily associated with contaminated drinking water and poor sanitation, untreated or poorly treated wastewater can contribute to the spread of this pathogen. Proper wastewater treatment and disinfection are crucial in preventing cholera outbreaks.

6.11. Wastewater born disease

Wastewater can serve as a vehicle for the transmission of various diseases, commonly referred to as wastewater-borne diseases or waterborne diseases. These diseases are caused by pathogens, including bacteria, viruses, protozoa, and helminths, which can contaminate water sources through improper disposal or inadequate treatment of wastewater. Here are some examples of wastewater-borne diseases:

- **Gastroenteritis:** Gastroenteritis is characterized by inflammation of the gastrointestinal tract and symptoms such as diarrhea, vomiting, abdominal pain, and fever. Several pathogens, including bacteria like Escherichia coli, Salmonella, Campylobacter, and viruses like Norovirus and Rotavirus, can be transmitted through contaminated wastewater and cause gastroenteritis.
- **Hepatitis A:** Hepatitis A is a viral infection that primarily affects the liver. It is transmitted through the fecal-oral route, often via contaminated water or food. Inadequately treated wastewater can contain the Hepatitis A virus, posing a risk of infection if consumed or in contact with the mouth.
- **Typhoid Fever:** Typhoid fever is a bacterial infection caused by Salmonella typhi. It is transmitted through the ingestion of food or water contaminated with fecal matter containing the bacteria. In regions with inadequate sanitation and wastewater management, the improper disposal of wastewater can contribute to the spread of typhoid fever.
- **Cholera:** Cholera is an acute diarrheal disease caused by the bacterium Vibrio cholerae. It is primarily associated with poor sanitation and contaminated drinking water. Inadequately treated wastewater can introduce V. cholerae into water bodies, leading to the spread of cholera if consumed.

- **Polio:** Poliomyelitis, commonly known as polio, is a viral disease that can cause paralysis. The poliovirus is primarily transmitted through the fecal-oral route, and contaminated water sources, including wastewater, can serve as a means of transmission.
- **Cryptosporidiosis:** Cryptosporidiosis is a parasitic infection caused by the protozoan parasite Cryptosporidium. It can be transmitted through water contaminated with the parasite, including inadequately treated wastewater. Cryptosporidium is highly resistant to chlorine disinfection and can cause prolonged diarrhea, especially in individuals with weakened immune systems.

6.12. Waste water treatment

Wastewater treatment is the process of removing pollutants and contaminants from wastewater to make it safe for disposal or reuse. It involves a series of physical, chemical, and biological processes designed to remove suspended solids, organic matter, nutrients, pathogens, and other harmful substances. Here is an overview of the common steps involved in wastewater treatment:

Preliminary Treatment:

The wastewater undergoes preliminary treatment to remove large objects, such as debris, stones, and grit, through processes like screening and grit removal. This step helps protect downstream treatment processes and prevents damage to equipment.

Primary Treatment:

In the primary treatment stage, the wastewater is subjected to physical processes to separate suspended solids and settleable organic matter. It typically involves sedimentation or clarification, where heavier solids settle to the bottom as sludge, and lighter materials, known as primary effluent, are skimmed off the top.

Secondary waste water treatment:

Secondary wastewater treatment is a crucial step in the wastewater treatment process, following the primary treatment stage. It focuses on the biological degradation and removal of dissolved and colloidal organic matter that remains in the wastewater after primary treatment. The most common method used for secondary treatment is the activated sludge process, which involves the use of microorganisms to break down organic pollutants. Here is an overview of the secondary wastewater treatment process:

- **Activated Sludge Process:**In the activated sludge process, the wastewater is mixed with a culture of microorganisms, known as activated sludge, in an aeration tank. The microorganisms, including bacteria and protozoa, consume and metabolize the organic matter present in the wastewater, converting it into carbon dioxide, water, and additional microbial biomass.
- **Aeration:** Aeration is a vital component of the activated sludge process. Air or oxygen is introduced into the aeration tank to create an aerobic environment, promoting the growth and activity of aerobic microorganisms that degrade organic pollutants. The aeration also helps to mix the wastewater and maintain optimal conditions for microbial activity.
- **Sludge Settling:** After the wastewater has undergone aeration, it flows into a settling tank, also known as a secondary clarifier or sedimentation tank. The hydraulic flow velocity is reduced in this tank, allowing the activated sludge and any remaining suspended solids to settle to the bottom as sludge. The settled sludge is then returned to the aeration tank for further treatment, while the clarified wastewater, known as the secondary effluent, is collected from the top.
- **Return and Waste Sludge Treatment:** A portion of the settled sludge, called return sludge, is recycled and returned to the aeration tank to maintain a stable microbial population and ensure continuous treatment. The excess sludge, known as waste sludge or surplus activated sludge, is removed from the system for further treatment and disposal, such as sludge thickening, dewatering, digestion, or drying.
- **Trickling Filters:** Trickling filters are another biological treatment method for secondary wastewater treatment. They consist of a bed of porous media, such as rock or plastic, over which wastewater is distributed. Microorganisms grow on the media and degrade organic matter as the wastewater trickles down through the bed. The treated effluent then passes through a settling tank to separate solids before discharge.
- **Rotating Biological Contactors (RBC):** RBC is a variant of the trickling filter system. It utilizes a series of rotating discs or drums partially submerged in the wastewater. As the discs rotate, microorganisms attached to their surface come into contact with the wastewater,

promoting biological degradation of organic pollutants. The treated wastewater is then settled and discharged.

- **Sequencing Batch Reactors (SBR):** SBR is a batch process that combines several treatment steps within a single reactor tank. It operates in cycles, including fill, react, settle, and decant phases. The wastewater is mixed with microorganisms in the reactor, where biological treatment occurs. After the treatment phase, the sludge settles, and the clarified effluent is decanted for discharge. SBR systems offer flexibility and good nutrient removal capabilities.
- **Oxidation Ditches:** Oxidation ditches are circular or oval-shaped channels where wastewater is continuously circulated, providing an oxygen-rich environment for microbial degradation. The ditches can have a complete mix or plug-flow configuration. The microorganisms in the ditch consume organic matter, and the treated effluent is settled and discharged.
- **Membrane Bioreactors (MBR):** MBR combines biological treatment with membrane filtration. It uses an activated sludge process in combination with ultrafiltration or microfiltration membranes to separate treated effluent from the biomass. The membranes act as a physical barrier, allowing only clean water to pass through, resulting in high-quality effluent.
- **Constructed Wetlands:** Constructed wetlands are engineered systems that mimic natural wetlands to treat wastewater. They utilize wetland plants and microbial activity in the root zone to remove pollutants through biological, physical, and chemical processes. The wetland vegetation and the underlying substrate provide an environment for microbial growth and pollutant removal.
- **Effluent Quality Control:** The secondary effluent is monitored and tested for various parameters to ensure it meets the required water quality standards and regulatory guidelines. Additional treatment processes, such as tertiary treatment, may be implemented to further improve the quality of the effluent if needed.

The secondary treatment process significantly reduces the concentration of organic matter, suspended solids, and pathogens in the wastewater, resulting in improved water quality. However, it may not effectively remove nutrients such as nitrogen and phosphorus, which may require additional treatment steps or tertiary treatment processes.

Tertiary waste water treatment

Tertiary wastewater treatment involves various processes and chemical reactions to further refine the quality of the effluent. While specific chemical equations can vary depending on the treatment method and target contaminants. These are just a few examples of chemical reactions that occur during tertiary wastewater treatment are such as:

- **Chemical Precipitation (Phosphorus Removal):** Phosphorus removal is often achieved through chemical precipitation using metal salts, such as aluminum or iron salts. In this reaction, aluminum sulfate reacts with calcium dihydrogen phosphate to form aluminum phosphate, calcium sulfate, and sulfuric acid. Aluminum phosphate precipitates and can be separated from the wastewater, thereby removing phosphorus.

$$2Al_2(SO_4)_3 + 3Ca(H_2PO_4)_2 + 2H_2O \rightarrow AlPO_4 + 6CaSO_4 + 6H_2SO_4$$

- **Chlorination (Disinfection):** Chlorine compounds, such as chlorine gas (Cl_2) or sodium hypochlorite (NaOCl), are commonly used for disinfection in tertiary treatment. Chlorine gas dissolves in water to form hydrochloric acid (HCl) and hypochlorous acid (HOCl). Hypochlorous acid acts as a powerful disinfectant, capable of inactivating pathogens by damaging their cellular structures and genetic material.

$$Cl_2 + H_2O \rightarrow HCl + HOCl$$

$$HOCl \rightarrow H^+ + Cl^-$$

- **Ozonation (Advanced Oxidation**): Ozonation involves the use of ozone gas (O_3) for advanced oxidation and removal of organic compounds. Ozone reacts with organic compounds in the wastewater, leading to the formation of reaction intermediates. Additionally, ozone reacts with water to produce hydrogen peroxide (H_2O_2) and oxygen gas. Hydrogen peroxide further reacts with ozone to produce hydroxide ions (OH^-) and more oxygen gas, contributing to the overall oxidation process.

$$O_3 + \text{organic compounds} \longrightarrow \text{reaction intermediates}$$

$$O_3 + H_2O \rightarrow H_2O_2 + O_2$$

$$H_2O_2 + O_3 \rightarrow 2OH^- + 2O_2$$

Sludge Treatment

Throughout the treatment process, sludge is generated as a byproduct. Sludge treatment involves various methods to reduce its volume, stabilize it, and minimize its environmental impact. Techniques such as thickening, dewatering, digestion, and drying are employed to treat and manage sludge effectively.

Disinfection:

Disinfection is a critical step in wastewater treatment to inactivate or kill pathogenic microorganisms, making the treated water safe for discharge or reuse. Common disinfection methods include chlorination, UV disinfection, and ozone treatment.

Effluent Discharge or Reuse:

The final effluent can be discharged into receiving water bodies, such as rivers or oceans, after meeting regulatory standards for water quality. Alternatively, the treated wastewater can undergo additional processes for reuse in various applications like irrigation, industrial processes, or groundwater recharge, depending on local regulations and requirements.

6.13. Advance oxidation waste water treatment

Advanced oxidation processes (AOPs) are a group of treatment methods used for the degradation and removal of persistent organic compounds and contaminants in wastewater. They involve the use of powerful oxidants or reactive compounds to break down and transform organic pollutants into simpler, less harmful substances. Here are a few examples of AOPs along with their chemical equations:

- **Ozone-based Advanced Oxidation:**Ozone (O_3) is a strong oxidant that reacts with organic compounds through direct ozone oxidation or the formation of hydroxyl radicals ($°OH$) to degrade pollutants. Ozone reacts directly with organic compounds, leading to the formation of reaction intermediates. It also reacts with water to produce hydrogen peroxide (H_2O_2) and oxygen gas. Hydrogen peroxide can then react with hydroxyl radicals to generate water and additional hydroxyl radicals, contributing to the overall oxidation process.The reactions involved in ozone-based AOPs are such as

$$O_3 + \text{organic compounds} \longrightarrow \text{reaction intermediates}$$

$$O_3 + H_2O \rightarrow H_2O_2 + O_2$$

$$H_2O_2 + °OH \rightarrow H_2O + °OH$$

- **Fenton's Reagent:**

Fenton's reagent consists of hydrogen peroxide ($\mathrm{H_2O_2}$) and ferrous ions ($\mathrm{Fe^{3+}}$) and is used for the oxidative degradation of organic pollutants. in this process ferrous ions react with hydrogen peroxide to generate hydroxyl radicals (°OH) and hydroxide ions ($\mathrm{OH^-}$). The hydroxyl radicals then react with organic compounds to produce reaction intermediates. The reactions involved in Fenton's oxidation are:

$$\mathrm{Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + {}^{\circ}OH + OH^-}$$

$$\mathrm{{}^{\circ}OH} + \text{organic compounds} \longrightarrow \text{reaction intermediates}$$

- **Photocatalysis ($\mathrm{TiO_2}$):**

Photocatalysis involves the use of a semiconductor material, typically titanium dioxide ($\mathrm{TiO_2}$), activated by ultraviolet (UV) light to generate reactive species for pollutant degradation. When exposed to UV light, titanium dioxide generates electrons (e^-) and positive holes ($\mathrm{h^+}$). The holes react with water to produce hydroxyl radicals (°OH), while the electrons react with oxygen molecules ($\mathrm{O_2}$) to form superoxide radicals ($\mathrm{O_2^{-\bullet}}$). Both hydroxyl radicals and superoxide radicals can then react with organic compounds, leading to the degradation of pollutants.

$$\mathrm{TiO_2 + hv\ (UV\ light) \rightarrow e^- + h^+}$$

$$\mathrm{h^+ + H_2O \rightarrow {}^{\circ}OH + H^+}$$

$$\mathrm{e^- + O_2 \rightarrow O_2^{-\bullet}}$$

$$\mathrm{{}^{\circ}OH} + \text{organic compounds} \longrightarrow \text{reaction intermediates}$$

$$\mathrm{O_2^{-\bullet}} + \text{organic compounds} \longrightarrow \text{reaction intermediates}$$

6.13.1. Application of advance oxidation process:

1. AOPs are effective in the degradation of persistent organic compounds that are resistant to conventional treatment methods. These include various organic pollutants such as pharmaceuticals, personal care products, pesticides, industrial chemicals, and emerging contaminants.
2. AOPs can target and remove micropollutants, including endocrine-disrupting compounds and trace organic contaminants, which may have adverse effects on aquatic ecosystems and human health.

3. OPs can be used for advanced disinfection of wastewater, particularly for the inactivation of pathogenic microorganisms and viruses. The strong oxidizing properties of AOPs help in destroying the cell structures and genetic material of pathogens, providing a high level of microbial inactivation.
4. AOPs are effective in removing color and odor-causing compounds from wastewater, particularly those associated with industrial effluents. These processes can break down chromophores and organic compounds responsible for color and unpleasant odors, resulting in clearer and odor-free effluent.
5. OPs can be employed for the treatment of contaminated groundwater, particularly in cases where conventional methods are not sufficient to remove persistent contaminants. AOPs can degrade and transform organic compounds present in groundwater, contributing to the remediation of contaminated sites.
6. AOPs play a crucial role in wastewater reclamation and reuse. By effectively degrading organic pollutants and inactivating pathogens, AOP-treated effluent can be reused for non-potable purposes such as irrigation, industrial processes, and groundwater recharge.

6.14. Summary

Wastewater treatment and the management of industrial effluent are crucial processes to protect the environment, ensure public health, and promote sustainable water resources. Here is a summary of wastewater treatment and industrial effluent management: Wastewater treatment refers to the processes that remove pollutants and contaminants from wastewater before it is discharged back into the environment or reused. The treatment typically involves several stages, including primary, secondary, and tertiary treatment. In primary treatment, physical processes such as screening and sedimentation are used to remove large solid materials and suspended solids from wastewater. This step helps in reducing the organic load and prepares the wastewater for further treatment. Secondary treatment focuses on the removal of dissolved and colloidal organic matter and nutrients. Tertiary treatment is an advanced stage that further refines the quality of the effluent. It involves processes like filtration, disinfection, and nutrient removal. Filtration methods such as sand filtration and membrane filtration are used to remove remaining particles and microorganisms. Wastewater treatment and industrial effluent management are vital for protecting water resources and ecosystems. Through the implementation of effective treatment processes, adherence to regulations, and continuous improvement of industrial practices, we can mitigate the environmental impacts of wastewater and industrial effluent, ensuring a sustainable and clean water supply for present and future generations.

6.15. Terminal questions

Q.1: What is the waste water? Discuss the sources, sink and characteristics of waste water.

Answer:--

Q.2: Define the industrial effluents and its chemical compositions.

Answer:--

Q.3: What is the sludge and activated sludge?

Answer:--

Q.4: Discuss the chemical composition of sludge and activated sludge.

Answer:--

Q.5: What is eutrophication? Write types and sources of eutrophication.

Answer:--

Q.6: Write the role of soaps, detergents and phosphorus fertilizers in eutrophication.

Answer:--

6.16. Further suggested readings

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Block-3

PGEVS-102N

Environmental Chemistry

Rajarshi Tandon Open University, Prayagraj

Block- 3

Soil and Noise Pollution

UNIT -7
Soil Pollution

UNIT-8
Noise Pollution

UNIT-9
Industrial Pollution

PGEVS-102N

Rajarshi Tandon Open

University, Prayagraj

Environmental Chemistry

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Introduction

This third block of environmental chemistry consists of following three units:

Unit-7: This unit covers the chemical composition, sources and types of soil pollutants. The soil carbon, essential elements and soil fertility is discussed here. The cation and anion exchange capacity, exchangeable sodium percentage, ion exchange, pH and acidity of soil are discussed briefly.

Unit-8: This unit covers the sources; frequency, intensity and permissible ambient noise levels of noise. The effect on communication, impacts on life forms and humans and control measures of noise discussed briefly.

Unit-9: This unit covers the Industrial Pollution in which chemical solvents used in dyeing, tanning, metallurgical and platinum industry are discussed, the pollutants rising from burning of fossil fuels like coal, oil, natural gas and sources of other industrial pollutants such as petroleum, heavy metals pollution etc are also mentioned

Unit-7: Soil Pollution

Contents

7.1. Introduction

Soil contamination or soil pollution as part of land degradation is caused by the presence of xenobiotic (human-made) chemicals or other alteration in the natural soil environment. It is defined as the presence of toxic chemicals (pollutants or contaminants) in soil, in high enough concentrations to pose a risk to human health and/or the ecosystem. In the case of contaminants which occur naturally in soil, even when their levels are not high enough to pose a risk, soil pollution is still said to occur if the levels of the contaminants in soil exceed the levels that should naturally be present. It is a serious environmental concern since it harbours many health hazards. For example, exposure to soil containing high concentrations of benzene increases the risk of contracting leukaemia. All soils, whether polluted or unpolluted, contain a variety of compounds (contaminants) which are naturally present. Such contaminants include metals, inorganic ions and salts (e.g., phosphates, carbonates, sulfates, nitrates), and many organic compounds (such as lipids, proteins, DNA, fatty acids, hydrocarbons, PAHs, alcohols, etc.). However, the concentration of such substances in unpolluted soil is low enough that they do not pose any threat to the surrounding ecosystem. When the concentration of one or more such toxic substances is high enough to cause damage to living organisms, the soil is said to be contaminated.

7.2. Soil and its composition

Soil is an essential component of our environment and its quality can be maintained by land management. Soil is made up of broken-down rock materials of varying degree of fineness and changed in varying degree from the parent rocks by the action of different agencies, such that the growth of vegetation made possible. Soil is derived from the Latin word **solum**, which means **floor** or **ground**.Soil is a dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms. It is more or less loose and crumby part of the outer earth crust in which, by means of their roots, plants may or do find foot hold and nourishment and as well as other conditions essential to their growth.Soil is a natural body developed by natural forces acting on natural materials. It is usually differentiated into horizons from minerals and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constituents, chemical properties and composition and biological characteristics.

Composition of Soil

The soil consists of four major components, i.e., mineral matter, organic matter, soil air and soil water. All these components cannot be separated with much satisfaction because they are very intimately mixed with each other. The mineral matter forms the bulk of soil solids and a very small amount of the soil solids is occupied by organic matter.

Volumetric composition of mineral (inorganic) soil is.

1. **Mineral matter (45%),** obtained by the disintegration and decomposition of rocks;
2. **Organic matter(5%),** obtained by the decay of plant residues, animal remains and microbial tissues;
3. **Water, obtained(25%),** from the atmosphere and the reactions in soil (chemical, physical and microbial);
4. **Air or gases (25%),** from atmosphere, reactions of roots, microbes and chemicals in the soil

In fact, soil is the mixture of various inorganic and organic chemical compounds. The chief inorganic constituents of soil are the compounds of Ca, Al, Mg, Fe, Si, K and Na. Small amounts of the compounds of Mn, Cu, Zn, Co, B, I, and Fe etc. are also present in the soil. Soil solution also contains complex mixtures of minerals of carbonates, sulphates, chlorides, nitrates and also the organic salts of Ca, Mg, K, Na etc. The chief organic compounds of soil is humus, which contains a large number of organic compounds such as amino acids, proteins, aromatic compounds, sugar, alcohols, fats, oils, waxes, resins, tannins, lignin, pigment, purines and many other. As a result, humus is a black colored, homogeneous complex material.Physically, the soil consists of stones, large pebbles, dead plant twigs, roots leaves and other parts of the plants, fine sand, silt, clay and humus-derived from the decomposition of organic matter. In the organic matter of the portion of the soil, about 50% of the organic matter is composed of dead remains of the soil life in all stages of decomposition and the remaining 50% of the organic matter in the soil is alive. The living part of the organic matter consists of plant roots, bacteria, earthworms, algae, fungi, nematodes, actinomycetes and many other organisms including rodents and insects.

7.3. Soil pollution

Soil pollution refers to the presence of a chemical or substance out of place and/ or present at a higher than normal concentration that has adverse effects on any non-targeted organism (FAO and ITPS, 2015). Although the majority of pollutants have anthropogenic origins, some contaminants can occur naturally in soils as components of minerals and can be toxic at high concentrations. Soil pollution often cannot be directly assessed or visually perceived, making it a hidden danger. Soil contamination or soil pollution can occur either because of human activities or because of natural processes. However, mostly it is due to human activities. The soil contamination can occur due to the presence of chemicals such as pesticides, herbicides, ammonia, petroleum hydrocarbons, lead, nitrate, mercury, naphthalene, etc in an excess amount. However, the concentration of such substances in unpolluted soil is low enough that they do not pose any threat to the surrounding ecosystem. When the concentration of one or more such toxic substances is high enough to cause damage to living organisms, the soil is said to be contaminated. The diversity of contaminants is constantly evolving due to agrochemical and industrial developments. This diversity, and the transformation of organic compounds in soils by biological activity into diverse metabolites, makes soil surveys to identify the contaminants both difficult and expensive.

7.3.1. Types of soil pollutants

- **Biological agents:** Biological agents work inside the soil to introduce manures and digested sludge (coming from the human, bird and animal excreta) into the soil.
- **Agricultural practices:** The soil of the crops is polluted to a large extent with pesticides, fertilizers, herbicides, slurry, debris, and manure.
- **Radioactive substances:**Radioactive substances such as Radium, Thorium, Uranium, Nitrogen, etc. can infiltrate the soil and create toxic effects.
- **Urban waste:**Urban waste consists of garbage and rubbish materials, dried sludge and sewage from domestic and commercial waste.
- **Industrial wastes:** Soil, pesticides, textiles, drugs, glass, cement, petroleum, etc. are produced by paper mills, oil refineries, sugar factories, petroleum industries and others as such.

7.3.2. Common sources of soil pollution

Agricultural practices	pesticides, herbicides, and chemical fertilizers
Mining activities	heavy metals and other toxic substances
Improper waste disposal:	solid waste, such as plastics, household garbage, and electronic waste, etc.
Accidental spills	spills out of chemicals, liquid spillage or hazardous materials, such as oil spills,

Industrial and urban sources	House hold and industrial waste disposal, metals and solvent release form mining and painting industries

7.3.3. Impacts of soil on nature

The impacts of soil pollution are far-reaching and can have serious consequences. Some of the effects of soil pollution include:

Reduced agricultural productivity: Soil pollution can decrease soil fertility, impair nutrient cycling, and disrupt the balance of beneficial soil organisms, leading to lower crop yields and poor agricultural productivity.

Contamination of groundwater: Pollutants in the soil can leach into the groundwater, contaminating water sources and posing risks to human health when consumed.

Damage to ecosystems: Soil pollution can disrupt soil ecosystems, affecting plant and animal life in the area. Soil organisms such as worms, bacteria, and fungi play crucial roles in maintaining soil health, and their disruption can have cascading effects on the entire ecosystem.

Health risks: Soil pollution can lead to the accumulation of toxic substances in crops, which, when consumed by humans or animals, can cause health problems such as heavy metal poisoning or exposure to harmful chemicals.

7.3.4. Effects of soil pollution on human health

- congenital disorders (chromium, lead and other metals, petroleum, solvents, and many pesticides and herbicide)
- leukemia (benzene)
- kidney damage (Mercury and cyclodienes)
- liver toxicity (PCBs and cyclodienes)
- neuromuscular blockage (organophosphates and carbonates)
- depression of the central nervous system (chlorinated solvents)
- headache, nausea, fatigue, eye irritation and skin rash (chemicals)
- some irreversible diseases other chronic health conditions

- can cause death by exposure via direct contact, inhalation or ingestion of contaminants in groundwater contaminated through soil

7.4. Characteristics of polluted soil

Polluted soil exhibits several characteristic features that can indicate its contamination. Here are some common characteristics of polluted soil:

- **Discoloration:** Polluted soil may have an abnormal color compared to healthy soil. It can appear dark, black, or discolored due to the presence of pollutants.
- Unpleasant odor: Contaminated soil often emits strong and unpleasant odors, which may be caused by the presence of chemicals, organic matter decomposition, or microbial activity associated with pollution.
- **Reduced fertility:** Polluted soil generally has decreased fertility compared to uncontaminated soil. The presence of pollutants can disrupt nutrient cycles, inhibit the growth of beneficial soil organisms, and impact the availability of essential nutrients for plants.
- **Poor drainage:** Contaminated soil may have altered physical properties, such as poor drainage. The pollutants can affect the soil structure, leading to compaction or clogging, reducing the soil's ability to absorb and retain water.
- **Altered pH levels:** Pollution can cause changes in soil pH levels. Certain contaminants, such as acid rain or industrial discharges, can make the soil more acidic, while others may make it more alkaline. These pH changes can affect nutrient availability and impact plant growth.
- **Accumulation of toxic substances:** Polluted soil often contains elevated levels of toxic substances such as heavy metals (e.g., lead, mercury, cadmium) or organic pollutants (e.g., pesticides, hydrocarbons). These substances can persist in the soil for extended periods and pose risks to human health, wildlife, and plants.
- **Reduced biodiversity:** Soil pollution can lead to a decline in soil biodiversity. The presence of pollutants can harm or kill soil microorganisms, worms, and other beneficial organisms essential for soil health and ecosystem functioning.

- **Contamination of groundwater:** Polluted soil can act as a source of groundwater contamination. Pollutants present in the soil can leach into the groundwater, potentially affecting drinking water sources and causing environmental and health concerns.

7.5.Soil pH and acidity of soil

Soil pH and soil acidity are closely related concepts that describe the chemical properties of soil. To measure soil pH and acidity, soil samples are typically collected and tested using a pH meter or a pH testing kit. The results provide valuable information for determining soil health and suitability for specific plants. If soil acidity is too high, it can be amended by adding agricultural lime or other materials that neutralize the acidity, thereby raising the pH and making the soil more suitable for plant growth. Soil pH and acidity are critical factors that influence the health and productivity of soil, which in turn, affects the growth of plants and crops.

Soil pH: Soil pH is a measure of the acidity or alkalinity of soil. It indicates the concentration of hydrogen ions (H^+)in the soil solution. The pH scale ranges from 0 to14, with pH 7 being considered neutral. Values below 7 indicate acidic soil, while values above 7 indicate alkaline (basic) soil. Most plants prefer a slightly acidic to neutral pH range for optimal growth, typically between pH 6 and 7.5.

Acidic Soil:
pH Range: 4.5-5.5
Example: Many coniferous forests, such as those dominated by pine trees, tend to have naturally acidic soils.
Neutral Soil:
pH Range: 6.5-7.5
Example: Most agricultural soils aim to maintain a neutral pH level, as it is generally suitable for a wide range of crops.
Alkaline Soil:
pH Range: 8.0-9.0
Example: Arid and semi-arid regions, like deserts, can often have naturally alkaline soils due to low rainfall and high evaporation rates.

Soil Acidity: Soil acidity refers specifically to the presence of excess hydrogen ions (H^+) in the soil, resulting in a low pH. It is primarily caused by the presence of acidic substances in the soil, such as organic matter decomposition, acidic parent materials, or acidic fertilizers. Acidic soils can have detrimental effects on plant growth and nutrient availability. They can also increase the solubility of toxic elements like aluminum and manganese, which can further inhibit plant growth.

The pH and acidity of soil is crucial for selecting suitable plants, determining nutrient availability, and implementing appropriate soil management practices. Conducting a soil test specific to your location and intended crops is recommended for accurate assessment and recommendations regarding pH and acidity levels.

Measurement of Soil pH

Soil pH can be measured using a pH meter or pH paper, which provides a quick and accurate assessment. Another method involves mixing soil with a pH indicator solution and comparing the resulting color to a standardized chart. The most common method is the use of a glass electrode pH meter, which offers precise readings.

Factors Influencing Soil Acidity:

Several factors can influence soil acidity:

Parent Material: The geology of an area plays a significant role in determining soil pH. Soils derived from limestone are often more alkaline, while those from granite or sandstone tend to be more acidic.

1. **Climate:** Precipitation patterns can affect soil pH. Areas with high rainfall may have leached nutrients, making the soil more acidic.
2. **Organic Matter**: The decomposition of organic matter can release acids into the soil, contributing to increased acidity.
3. **Vegetation:** The type of vegetation covering the soil can influence its pH. Coniferous trees, for example, can create acidic conditions due to the release of organic acids.
4. **Agricultural Practices**: The use of fertilizers and the crops grown can affect soil pH. Overuse of certain fertilizers may lead to increased acidity.

Significance in Agriculture:

Soil pH plays a crucial role in agriculture. Different plants have varying pH requirements. For example, most crops thrive in slightly acidic to neutral soils (pH 6 to 7). Soil that is too acidic or alkaline can lead to nutrient deficiencies as some essential elements become less available to plants. Adjusting soil pH through practices like liming (raising pH) or sulfur application (lowering pH) is common in agriculture to optimize crop growth and yield.

Environmental Implications:

Soil acidity can also impact the environment. Highly acidic soils can harm aquatic ecosystems when rainwater washes acidic substances into rivers and lakes. Acid rain, which is caused by emissions of sulfur dioxide and nitrogen oxides from industrial and transportation sources, can further exacerbate soil and water acidity, negatively affecting aquatic life and vegetation.

7.6. Soil carbon

Soil carbon refers to the carbon stored in the soil as organic matter. It plays a vital role in the carbon cycle and has important implications for climate change mitigation and soil health.Soil carbon is primarily derived from plant material that decomposes and accumulates in the soil over time. When plants photosynthesize, they absorb carbon dioxide (CO_2) from the atmosphere and convert it into organic compounds through photosynthesis. Some of these organic compounds are transferred to the soil through root exudates, dead plant material, and the decomposition of plant residues.There are two main forms of soil carbon: labile carbon and stable carbon. Labile carbon consists of fresh organic matter that decomposes relatively quickly, providing energy and nutrients for soil microorganisms. Stable carbon, on the other hand, is more resistant to decomposition and can persist in the soil for longer periods, often in the form of humus.Soil carbon has several important functions:

Climate regulation: Soil carbon sequestration helps mitigate climate change by removing $CO_2$from the atmosphere and storing it in the soil. This process is known as carbon sequestration. Increasing soil carbon levels can help offset greenhouse gas emissions and contributes to the reduction of atmosphericCO_2.

Nutrient cycling: Soil carbon is a vital component of nutrient cycling in ecosystems. It provides a source of energy for soil organisms that decompose organic matter, releasing nutrients like nitrogen, phosphorus, and sulfur into the soil. These nutrients are essential for plant growth and ecosystem productivity.

Soil fertility and structure: Soil carbon improves soil fertility by enhancing nutrient retention, water-holding capacity, and cation exchange capacity. It also plays a crucial role in soil aggregation, which affects soil structure, porosity, and aeration. Soils with higher carbon content generally have better fertility and structure, supporting healthier plant growth.

Water management: Soil carbon influences the water-holding capacity of soils. Soils with higher carbon levels have better water infiltration and retention, reducing the risk of erosion, runoff, and drought. This can improve water availability for plants and contribute to sustainable water management.

Overall, soil carbon is a key component of healthy and sustainable soils. Its conservation and management are essential for maintaining soil fertility, supporting agricultural productivity, mitigating climate change, and promoting ecosystem resilience.

7.7. Essential elements of soil

Soil is composed of various essential elements that are necessary for plant growth and the functioning of ecosystems. These elements, often referred to as macronutrients and micronutrients, play vital roles in plant metabolism and overall soil fertility. The essential elements are obtained by plants from the soil through their root systems. Adequate availability of the elements in the soil is crucial for healthy plant growth and development. Soil testing and nutrient management practices help ensure that these essential elements are present in appropriate amounts for optimal plant nutrition. Here are some of the essential elements found in soil are as followings

Macronutrients:

i. **Nitrogen (N):** Nitrogen is a crucial component of proteins, enzymes, and chlorophyll, essential for plant growth and development.

ii. **Phosphorus(P):** Phosphorus is involved in energy transfer processes, root development, flowering, and fruiting.

iii. **Potassium (K):** Potassium is important for water regulation, photosynthesis, enzyme activation, and overall plant health.

iv. **Calcium (Ca):** Calcium contributes to cell wall structure, root development, and nutrient uptake.

v. **Magnesium (Mg):** Magnesium is a central component of chlorophyll and plays a vital role in photosynthesis.

vi. **Sulfur (S):** Sulfur is necessary for protein synthesis, enzyme activation, and nutrient utilization.

Micronutrients:

i. **Iron (Fe):** Iron is essential for chlorophyll synthesis and plays a role in enzyme reactions.

ii. **Manganese (Mn):** Manganese is involved in photosynthesis, enzyme activation, and nitrogen metabolism.

iii. **Zinc (Zn):** Zinc is crucial for enzyme activity, growth regulation, and hormone synthesis.

iv. **Copper (Cu):** Copper participates in photosynthesis, respiration, and lignin synthesis.

v. Boron (B): Boron is necessary for cell wall formation, pollen development, and carbohydrate metabolism.

vi. **Molybdenum (Mo):** Molybdenum is essential for nitrogen fixation and enzyme reactions.

vii. **Nickel (Ni):** Nickel is required for some enzyme systems, including nitrogen metabolism.

7.8. Soil fertility

Soil fertility refers to the ability of soil to support healthy plant growth and productivity. It is determined by the presence and availability of essential nutrients, organic matter, and soil microorganisms. Soil fertility is influenced by several factors, including soil type, climate, land use, and management practices. Soil fertility is essential for maintaining agricultural productivity and ecosystem health. A fertile soil provides plants with the necessary nutrients and water, promotes root growth and development, and supports the soil food web. The soil food web is a complex network of organisms that interact with each other and with plants, playing crucial roles in nutrient cycling, soil structure, and organic matter decomposition. Several factors can affect soil fertility, including:

- **Soil texture:** Soil texture refers to the relative proportions of sand, silt, and clay in the soil. Soil texture influences the soil's water-holding capacity, aeration, and nutrient retention.
- **Soil organic matter:** Soil organic matter is composed of decomposing plant and animal material. It plays a crucial role in maintaining soil fertility by providing nutrients, enhancing soil structure, and promoting the activity of soil microorganisms.
- **Nutrient availability:** The availability of essential nutrients, such as nitrogen, phosphorus, and potassium, is critical for plant growth and productivity. Soil testing can help identify nutrient deficiencies and guide nutrient management practices.
- **Soil pH:** Soil pH influences nutrient availability, plant growth, and soil microorganism activity. Different plants thrive under different pH levels, and management practices may need to be adjusted to maintain optimal soil pH.
- **Soil microorganisms:** Soil microorganisms, including bacteria, fungi, and protozoa, play critical roles in nutrient cycling, organic matter decomposition, and disease suppression. Management practices that promote soil microbial activity can enhance soil fertility.

Soil fertility can be managed through various practices, including crop rotations, cover cropping, nutrient management, conservation tillage, and organic farming. These practices aim to maintain or enhance soil organic matter, nutrient availability, and soil microbial activity, promoting healthy plant growth and ecosystem sustainability.

7.9. Soil ion exchange

Soil ion exchange is a fundamental process in soil chemistry that has significant implications for nutrient availability, soil fertility, pH regulation, and overall plant growth. Here is some key significance of soil ion exchange:

- **Nutrient availability:** Soil ion exchange plays a critical role in making essential nutrients available to plants. Nutrients like calcium ($\mathrm{Ca^{2+}}$), magnesium ($\mathrm{Mg^{2+}}$), potassium ($\mathrm{K^{+}}$), and ammonium ($\mathrm{NH_4^+}$) are positively charged cations that can be attracted and retained by negatively charged exchange sites in the soil. This exchange process helps retain nutrients in the root zone, preventing their leaching away and making them accessible for plant uptake over time.

- **pH regulation:** Soil ion exchange also influences soil pH regulation. The exchange of hydrogen ions (H^+) and other cations on exchange sites can affect the soil's acidity or alkalinity. For example, the release of hydrogen ions from exchange sites can increase soil acidity, while the exchange of calcium or magnesium ions can help neutralize soil acidity. The balance of cations on exchange sites can influence the soil's pH, which in turn affects nutrient availability and plant growth.
- **Toxicity mitigation:**

  Soil ion exchange can help mitigate the toxic effects of certain ions. For instance, excessive concentrations of aluminum (Al^{3+}) or manganese (Mn^{2+}) ions can be toxic to plants. Soil ion exchange can bind these toxic ions to exchange sites, reducing their availability and minimizing their negative impact on plant health.
- **Soil fertility**:

  The ability of soil to retain and release nutrients through ion exchange is vital for soil fertility. Efficient ion exchange ensures that essential nutrients are available to plants, supporting their growth, yield, and overall health. Additionally, soil fertility is closely related to the presence of exchangeable cations and anions, as they contribute to nutrient cycling, organic matter decomposition, and the activities of soil microorganisms.
- **Cation exchange capacity**:

  Cation exchange capacity (CEC) is a measure of the soil's ability to retain and exchange cations (positively charged ions) between the soil particles and the soil solution. It is an important property of soil that influences nutrient availability, soil fertility, and the soil's ability to retain essential nutrients for plant uptake. The CEC of a soil is determined by the type and amount of clay minerals, organic matter content, and soil pH. Clay minerals and organic matter are primarily responsible for providing sites with negative charges, known as exchange sites or exchangeable sites, where cations can be attracted and held. Common exchangeable cations include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and hydrogen (H^+).The importance of CEC lies in its role in nutrient retention and availability. When essential plant nutrients such as calcium, magnesium, and potassium are present as cations in the soil solution, they can be adsorbed onto the negatively charged exchange sites of the soil particles. This adsorption helps to prevent these nutrients from being easily leached away by rainfall or irrigation, making them available for plant roots to uptake over time. Furthermore, the CEC also affects soil pH. The exchange sites can be occupied by hydrogen ions (H^+), which are associated with soil acidity. Soils with a high CEC are generally more resistant to changes in pH because they have a greater capacity to retain and buffer hydrogen ions, helping to maintain a relatively stable soil pH. Soil testing is often conducted to determine the CEC of a soil. This information can guide nutrient management practices, such as determining fertilizer application rates, selecting appropriate soil amendments, and understanding the soil's capacity to retain and release nutrients. The cation exchange capacity is a measure of the soil's ability to retain and exchange cations. It plays a vital role in nutrient availability, soil fertility, and pH regulation, impacting plant growth and the overall health of agricultural and natural ecosystems.

- **Anion exchange capacity**:

  Anion exchange capacity (AEC) is the ability of soil to retain and exchange anions (negatively charged ions) in the soil solution. It is a property similar to cation exchange capacity but focuses on anions rather than cations. Anions such as nitrate (NO_3^-), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), and others are essential nutrients for plants. The AEC of the soil determines the soil's ability to retain and release these anions for plant uptake. Similar to CEC, AEC is influenced by factors such as soil mineralogy, organic matter content, and soil pH. Clay minerals and organic matter contribute to the AEC by providing negatively charged exchange sites where anions can be attracted and held. Soil pH also plays a role in anion exchange capacity, as it affects the availability and mobility of anions in the soil. Anion exchange capacity is important for nutrient cycling and availability in the soil. Just as cations can be retained on exchange sites and slowly released to plants, anions can also be adsorbed and held in the soil, preventing them from being easily leached out of the root zone. This allows plants to access anions over time as they are released from the exchange sites. Understanding the anion exchange capacity of the soil can be helpful in managing nutrient availability and preventing nutrient losses. Soil testing can provide information about the AEC, guiding fertilizer recommendations and nutrient management practices to ensure optimal nutrient uptake by plants. It's worth noting that while cation exchange capacity (CEC) is a more commonly discussed soil property, anion exchange capacity (AEC) is also important for nutrient retention and availability in the soil. Both CEC and AEC contribute to the overall nutrient-holding capacity of the soil and influence plant growth and productivity.

- **Exchangeable sodium percentage:**

  The exchangeable sodium percentage (ESP) is a measure used to evaluate the sodicity or sodium hazard of a soil. It represents the percentage of exchangeable sodium relative to the total exchangeable cations in the soil. When soils have a high ESP, it indicates that a significant portion of the exchangeable cations in the soil are sodium ions (Na^+). This can have adverse effects on soil structure, water infiltration, and nutrient availability, leading to soil degradation and reduced plant growth. A high ESP is often associated with sodic soils, which are characterized by their high sodium content and poor soil structure. Sodic soils tend to have dispersed clay particles that result in low permeability, reduced water infiltration, and increased susceptibility to erosion. They may also exhibit a crusty or hard surface when dry and a sticky, compacted texture when wet. Managing soils with high ESP involves improving soil structure and reducing the sodium content. This can be achieved through practices such as: **Soil amendment:** Adding amendments like gypsum (calcium sulfate) to the soil can help replace sodium ions with calcium ions (Ca^{2+}), which improves soil structure and reduces the effects of sodicity.

  Understanding soil ion exchange processes and managing nutrient availability through practices such as fertilization, pH adjustment, and soil amendment helps optimize soil fertility and promote healthy plant growth. Soil testing and analysis play a crucial role in determining the ion exchange properties of soil and guiding appropriate nutrient management strategies.

7.10. Prevention and control of soil pollution

Prevention and control of soil pollution are crucial for safeguarding human health, preserving ecosystems, and maintaining sustainable agricultural practices. some key strategies and measures for preventing and controlling soil pollution are as followings

Sustainable agriculture practices: Adopting sustainable agricultural practices can help prevent soil pollution. This includes minimizing the use of chemical fertilizers, pesticides, and herbicides, promoting organic farming methods, crop rotation, integrated pest management, and precision agriculture techniques. These practices reduce the input of harmful substances into the soil and promote soil health.

Soil erosion control: Soil erosion contributes to soil degradation and pollution. Implementing erosion control measures such as contour plowing, terracing, and planting vegetation cover can prevent the loss of topsoil and the associated contaminants.

Environmental regulations and policies: Governments and regulatory bodies play a critical role in preventing and controlling soil pollution. Implementing and enforcing environmental regulations, setting pollution control standards, and promoting sustainable practices help reduce soil contamination. Regular monitoring and assessment of soil quality are also essential to identify and address potential pollution sources.

Industrial pollution control: Industries should adopt pollution prevention measures to minimize the release of pollutants into the environment. This includes implementing proper treatment and containment systems, using cleaner production technologies, and adhering to strict environmental regulations.

Education and awareness: Creating awareness among the public, industries, and agricultural communities about the importance of soil pollution prevention is crucial. Education programs, campaigns, and training initiatives can promote responsible practices, encourage pollution reduction, and foster a sense of environmental stewardship.

It is important to note that preventing soil pollution requires a multi-faceted approach involving collaboration among governments, industries, agricultural sectors, scientific communities, and the public. By implementing these strategies and measures, we can minimize soil pollution, protect soil resources, and ensure a sustainable environment for future generations.

7.11. Nitrogen cycle

The nitrogen cycle is a crucial biogeochemical cycle that describes the movement and transformation of nitrogen in various forms through the Earth's atmosphere, soil, water bodies, and living organisms. Nitrogen enters the living world via free-living and symbiotic bacteria, which incorporate nitrogen into their macromolecules through nitrogen fixation (conversion of N_2). Cyanobacteria live in most aquatic ecosystems where sunlight is present; they play a key role in nitrogen fixation. The nitrogen cycle can be divided into five main processes: nitrogen fixation, nitrification, assimilation, ammonification, and denitrification. Each of these processes contributes to the overall cycling of nitrogen in different forms.

Nitrogen Fixation:

Nitrogen fixation is the conversion of atmospheric nitrogen (N_2) into a form that can be used by living organisms. This process can be achieved by both biological and non-biological means. Some nitrogen-fixing bacteria, such as Rhizobium, live in the root nodules of leguminous plants (e.g., soybeans, clover) and convert atmospheric nitrogen into ammonia (NH_3), a process known as biological nitrogen fixation. Two kinds of nitrogen-fixing bacteria are known: free-living or non-symbiotic bacteria, including the cyanobacteria (or blue-green algae), Anabaena and Nostoc and genera such as Azotobacter, Beijerinckia, and Clostridium and mutualistic or symbiotic bacteria such as Rhizobium, associated with leguminous plants and certain Azospirillum species, associated with cereal grasses. Biological nitrogen fixation can be represented by the equation, in which two moles of ammonia are produced from one mole of nitrogen gas, at the expense of 16 moles of ATP and a supply of electrons and protons (hydrogen ions). Therefore, this fixation is costly process.

$$N_2 + 8H + 8e^- + 16ATP \rightarrow 2NH_3 + H_2 + 16ADP + 16Pi$$

Non symbioticnitrogen fixation

- Non symbiotic nitrogen fixation is done by free-living (nonsymbiotic) bacteria, includes the cyanobacteria (or blue-green algae) *Anabaena* and *Nostoc* and genera such as *Azotobacter*, *Beijerinckia*, and *Clostridium.*
- In the roots of grass and cereal plants no nodules are formed like symbiotic bacteria. The bacteria Azospirillumbransilense, pseudomonas, Bacillus grow in the rizosphere in close contact with the root and involved in the other cortical regions of the roots and fix nitrogen.

Symbiotic nitrogen fixation

- Nitrogen is also fixed by microbes symbiotically including such as *Rhizobium*, associated with leguminous plants (e.g., various members of the pea family); *Frankia*, associated with certain dicotyledonous species (actinorhizal plants); and certain *Azospirillum* species, associated with cereal grasses.
- Root nodules are also found in the certain non-leguminous plants which also fix nitrogen e.g. In alder and alnus the actinomycetes is involved in nodules and fix nitrogen quite efficiently and play significant role on the nitrogen balance of some forest ecosystem.

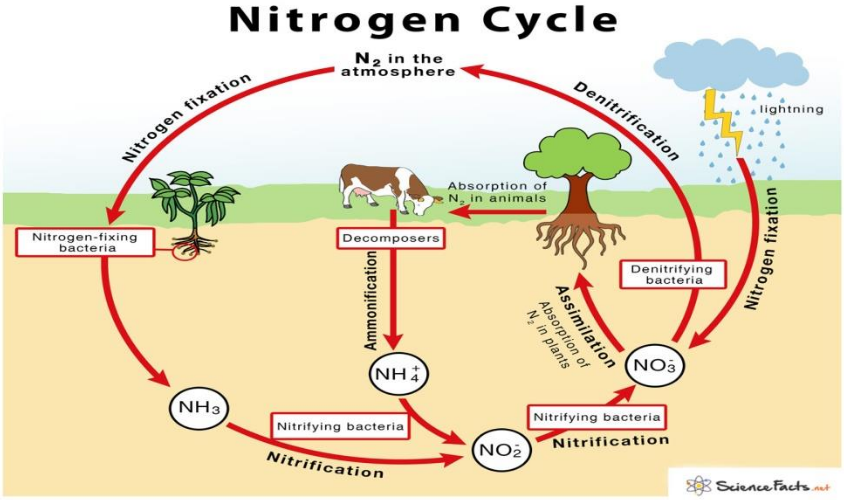
Associative symbiotic nitrogen fixation

- Nitrogen is also fixed by microorganism through non nodulation for example, the cyanobacteria, Anabaena azollae forms symbiotic association with Azolla Nostoc is found in the stem of Gunnera macrophylla. Azotobacter paspali develops colonies below mucilaginous sheath of paspalum notatum and fix atmospheric nitrogen.
- The process of N_2 fixation occurs in nodule is mediated by the enzyme, called nitrogenase and leghaemoglobin (which mediates the reduction of N_2 to ammonia) firstly, this enzyme was extracted from the anaerobic di nitrogen fixer Clostridumpasteurianum.
- The nitrogenase has 2 components i.e., Mo-Fe protein (molybdoferredoxin) and Fe-protein (azoferredoxin).The nitrogenase catalyzes the conversion of atmosphere di-nitrogen (N_2) to $2NH_3$. The ammonia is the first stable product of nitrogen fixation.

Later, this enzyme has been isolated from most of other N_2fixing bacteria. The mechanism of N_2 fixation appears to be quite similar in most N_2fixing prokaryotes. The enzyme has been fairly well characterized and the enzyme from these different systems share common properties allowing a unified single description of nitrogenase.

$$\mathrm{N_2 + 8H + 8e^- + 16ATP \xrightarrow[nitrogenase]{Mg^{2+}} 2NH_3 + H_2 + 16ADP + 16Pi}$$

During nitrogen fixation, the free di-nitrogen first bound to Mo-Fe protein and is not released until completely reduced to ammonia. The reduction of di-nitrogen is a stepwise reaction in which many intermediates are formed to form ammonia (NH_3) which is protonated at physiological pH to form NH_4^+.



Nitrification:

Nitrification is the process by which ammonia (NH_3) is converted into nitrites (NO_2^-) and nitrates (NO_3^-) by nitrifying bacteria. Nitrification occurs in two steps. First, ammonia is oxidized to nitrite by bacteria called ammonia-oxidizing bacteria (AOB). Then, nitrite is further oxidized to nitrate by bacteria called nitrite-oxidizing bacteria (NOB).

$$\text{Step 1: } 2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H^+ + 2H_2O$$

$$\text{Step 2: } 2NO_2^- + O_2 \rightarrow 2NO_3^-$$

Assimilation of nitrate :

Nitrogen assimilation is the formation of organic nitrogen compounds like amino acids from inorganic nitrogen compounds present in the environment. In this process Nitrogen fixed by plant is converted into organic molecules such as protein, DNA, RNA etc.Plants absorb nitrogen from the soil in the form of nitrate (NO_3^-) and ammonium (NH_4^+). Ammonium ions are absorbed by the plant via ammonia transporters.

Plants absorb nitrogen from the soil in the form of nitrate (NO_3^-) and ammonium (NH_4^+). In aerobic soils where nitrification can occur, nitrate is usually the predominant form of available nitrogen that is absorbed. However, this is not always the case as ammonia can predominate in grassland and in flooded, anaerobic soils like rice paddies. Plant roots themselves can affect the abundance of various forms of nitrogen by changing the pH and secreting organic compounds or oxygen. This influences microbial activities like the inter-conversion of various nitrogen species, the release of ammonia from organic matter in the soil and the fixation of nitrogen by non-nodule-forming bacteria.

Nitrogen assimilation requires the reduction of nitrate to ammonium, followed by ammonium assimilation into amino acids. Nitrate reduction takes place in both roots and shoots but is spatially separated between the cytoplasm where the reduction takes place and plastids/chloroplasts where nitrite reduction occurs.

In nitrogen assimilation, the N_2 fixation results is NH_4^+formation, which reacts with organic acids and form amino acids which is mediated by ammonia assimilating enzyme.

GS–Glutaminesynthetase

GOGAT–Glutamatesynthese

GDH – Glutamate dehydrogenase

Protein and nucleic acid of dead plants and animal residue or excreted products of animal are degraded by microorganism with the liberation of ammonium. This is called ammonification. For this process, proteolysis and amino acid degradations are involved.

$$\text{Protien} \rightarrow \text{Amino acids}$$

Amino acids are degraded by microbial activity and ammonia is released.

$$\text{Alanine} + \frac{1}{2}O_2 \xrightarrow[\text{deminase}]{\text{analine}} \text{Pyruvic acid} + NH_3$$

However, the reduction of nitrate into ammonia is called nitrogen assimilation mostly occurs in root tissues and then transported to shoot through xylem. The overall summary of nitrate reduction is as

$$NO_2^- + 8e^- + 10H^+ \rightarrow NH_4^+ + 3H_2O$$

In first step the nitrate in converted in to nitrate; the reaction is catalyzed by enzyme-nitrate reductase. This step occurs in cytosol outside of any organelles and requires NADH and electron donor.

$$NADH + H^+FAD \rightarrow NAD^+ + FADH_2$$

$$FADH_2 + (Oxi)Mo \rightarrow (Red)Mo + 2H^+ + FAD$$

$$(Red)Mo + 2H^+ + NO_3^- \rightarrow (Oxi)Mo + NO_2$$

In second step, the nitrite is reduced to ammonium. The reaction is catalyzed by enzyme nitrite reductase. The most probably electron donor in the reaction appears to be reduced Ferredoxin. The Ferredoxin is reduced in the light reaction of photosynthesis in green leaves. Nitrate reduction into nitrite is catalyzed in the cytosol by the enzyme nitrate reductase. The overall reaction of nitrate reduction is as follows

$$NO_2 + 6\,e^- + 8H^+ \rightarrow 2NH_3 + H_2O$$

Ammonification:

Ammonification, also known as mineralization, is the conversion of organic nitrogen compounds, such as proteins and urea, into ammonia (NH_3) by decomposer bacteria and fungi. This process occurs during the decomposition of dead organisms, animal waste, and organic matter.

$$\text{Organic nitrogen compounds} \rightarrow NH_3$$

Importance of Nitrogen Cycle

1. Helps plants to synthesize chlorophyll from the nitrogen compounds.
2. Helps in converting inert nitrogen gas into a usable form for the plants through the biochemical process.
3. In the process of ammonification, the bacteria help in decomposing the animal and plant matter, which indirectly helps to clean up the environment.
4. Nitrates and nitrites are released into the soil, which helps in enriching the soil with the necessary nutrients required for cultivation.
5. Nitrogen is an integral component of the cell and it forms many crucial compounds and important biomolecules.

Denitrification:

Denitrification is the final step of the nitrogen cycle, where nitrates (NO_3^-) are converted back into nitrogen gas (N_2) and released into the atmosphere. This process is carried out by denitrifying bacteria under anaerobic conditions (low oxygen levels), such as in waterlogged soils or sediments.

$$2NO_3^- \rightarrow N_2 + 2NO_2^- + H_2O$$

These bacteria use nitrate as an electron acceptor, breaking it down into nitrogen gas, which is released back into the atmosphere. Denitrification helps to reduce the accumulation of excess nitrogen in ecosystems and maintain a balance in nitrogen availability.

Overall, the nitrogen cycle demonstrates the continuous movement and transformation of nitrogen through various forms in the environment, ensuring its availability for the growth and sustenance of living organisms.

7.12. Reclamation of polluted soil

The reclamation of polluted soil refers to the process of restoring contaminated soil to a healthier and more productive state. It involves remediation techniques aimed at reducing or removing pollutants and improving the soil's quality. Here are some common methods used in the reclamation of polluted soil:

Soil Remediation: Soil remediation involves the treatment of polluted soil to reduce or eliminate contaminants. Some common techniques include:

a) **Excavation and Removal:** Contaminated soil is excavated and transported to a designated disposal site, preventing further contamination.

b) **Bioremediation:** This method uses microorganisms, such as bacteria or fungi, to break down or metabolize pollutants in the soil. It can be achieved through techniques like bioaugmentation (adding specialized microorganisms) or bio-stimulation (providing optimal conditions for indigenous microorganisms).

c) **Phytoremediation:** Plants are used to remove, degrade, or immobilize pollutants in the soil. Different plants have specific abilities to absorb or break down contaminants. Examples include hyperaccumulating plants for heavy metal removal or rhizosphere-enhancing plants for promoting microbial activity.

d) **Chemical Remediation:** Chemical techniques involve the use of additives, such as activated carbon or chemicals that bind to contaminants, to reduce their mobility or toxicity.

Soil Amendment: Adding soil amendments can help improve the soil's physical, chemical, and biological properties. Common amendments include:

a) Organic Matter Addition: Compost, manure, or other organic materials are incorporated into the soil to enhance its fertility, structure, and water-holding capacity.

b) pH Adjustment: Lime or sulfur may be used to adjust soil pH if it has been adversely affected by pollutants.

c) Nutrient Addition: Fertilizers or specific nutrients are applied to replenish essential elements that may have been depleted or affected by pollution.

Soil Covering: In cases where complete soil remediation is not feasible, covering the polluted soil with an impermeable layer, such as a geomembrane, clay cap, or clean soil layer, can prevent the migration of contaminants and protect underlying groundwater.

Soil Management Practices: Implementing proper soil management practices can promote the recovery of polluted soil. This includes erosion control measures, responsible waste management, and sustainable agricultural practices to minimize the risk of recontamination.

The choice of reclamation method depends on various factors, including the type and extent of contamination, site conditions, cost-effectiveness, and regulatory requirements. It is essential to conduct a thorough site assessment and consult with environmental experts to determine the most appropriate reclamation approach. Reclamation of polluted soil requires careful planning, monitoring, and compliance with relevant regulations to ensure the effectiveness of the remediation process and minimize the environmental and health risks associated with soil pollution.

7.13. Summary

Soil pollution refers to the contamination of soil with substances that are harmful to the environment, human health, and the functioning of ecosystems. It is a significant environmental issue with wide-ranging impacts. Soil pollution is caused by various sources, including industrial activities, agricultural practices, improper waste disposal, mining operations, and urbanization. These activities introduce pollutants into the soil, leading to its degradation and reduced fertility. Common soil pollutants include heavy metals, pesticides, herbicides, industrial chemicals, petroleum hydrocarbons, and improper waste materials. Industrial pollution is a major contributor to soil contamination. Industries release toxic chemicals, heavy metals, and other pollutants into the environment through improper waste disposal, leaks, spills, and emissions. Industrial areas often have highly polluted soils, posing risks to human health and surrounding ecosystems. Mining activities, such as extraction and processing of minerals, can also introduce heavy metals and other harmful substances into the soil. Agricultural practices, while essential for food production, can also contribute to soil pollution. Excessive use of chemical fertilizers, pesticides, and herbicides leads to the accumulation of these substances in the soil, affecting soil health and biodiversity. Improper handling and disposal of agricultural waste, including crop residues and animal manure, can also contaminate the soil with pathogens and excess nutrients.

Improper waste management is a significant factor in soil pollution. Open dumping, uncontrolled landfills, and inadequate treatment of solid and hazardous waste release pollutants into the soil. Landfills that lack proper lining and leachates management systems can contaminate the surrounding soil and groundwater. Burning of waste materials also releases toxic compounds into the soil. Soil pollution has several adverse effects on the environment and human health. Contaminated soils can lead to the loss of soil biodiversity and ecological imbalances. It affects soil fertility, nutrient cycling, and the ability of plants to uptake nutrients. Soil pollution can also result in the contamination of groundwater, leading to water pollution and potential risks to human health. Soil pollution is a complex and significant environmental problem with detrimental effects on ecosystems and human well-being. Addressing soil pollution requires collective efforts, including policy interventions, technological advancements.

7.14. Terminal Question

Q.1. What are the soil pollutions? Write the soil pollutants and its sources.

Answer:--

Q.2. What do you understand form soil carbon? How it is useful for the soil productivity.

Answer:--

Q.3. Discuss the nitrogen cycles and its role for plant growth and development.

Answer:--

Q.4. What are essential elements of soil? Discuss the role of different elements of plant.

Answer:--

Q.5. Discuss the soil cation exchange and anion exchange capacity and its significance in soil fertility.

Answer:--

Q.6. Discuss the exchangeable sodium percentage.

Answer:---

7.15. Further suggested Readings

9. Environmental Science, Subhas Chandra Santra, new central book agency, 3rd Edition, 2011.

10. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.

11. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd.

12. Textbook of Environmental Chemistry and Pollution Control, S.S.Dara and D.D. Mishra, S Chand & Co Ltd.

Unit-8: Noise Pollution

Contents

8.1. Introduction

Noise pollution is the production of excessively high levels of sound which may cause loss of hearing. The main sources of noise pollution originated from human activities. According to the World Health Organization (WHO), noise pollution is the one of the most dangerous environmental threats to health. And according to the European Environment Agency (EEA), noise is responsible for 16,600 premature deaths and more than 72,000 hospitalizations every year in Europe alone.Not only does it hurt humans, it is bad for animals, too. According to the National Park Service (NPS) in the United States, noise pollution has an enormous environmental impact and does serious damage to wildlife. Experts say noise pollution can interfere with breeding cycles and rearing and is even hastening the extinction of some species. Noise pollution is a pervasive issue that adversely affects human health, wildlife, and the environment. It arises from various sources, including transportation, construction, industries, and recreational activities. Efforts to control and mitigate noise pollution involve legislation, standards, monitoring, public awareness, technological advancements, and sustainable urban planning. By addressing noise pollution, we can create healthier, more peaceful environments that enhance the well-being of both humans and the natural world.

Objectives

- To discuss source types and effects of noise pollution
- To discuss the Permissible ambient noise levels
- To discuss the impacts on life forms and humans
- To discuss control measures of noise pollution

8.2. Noise Pollution

Noise pollution is unwanted or disturbing sound in the environment that affects the health and well-being of humans and other living organisms. It is an invisible danger. It cannot be seen, but it is present nonetheless, both on land and under the sea.Noise pollution is unwanted or excessive sound that can have deleterious effects on human health, wildlife, and environmental quality. Noise pollution is commonly generated inside many industrial facilities and some other workplaces, but it also comes from highway, railway, and airplane traffic and from outdoor construction activities.Not all sound is considered noise pollution. The World Health Organization (WHO) defines noise above 65 decibels (dB) as noise pollution. To be precise, noise becomes harmful when it exceeds 75 decibels (dB) and is painful above 120 dB. As a consequence, it is recommended noise levels be kept below 65 dB during the day and indicates that restful sleep is impossible with nighttime ambient noise levels in excess of 30 dB.The energy in a sound wave can be measured using Decibels. The Decibel Meter shows examples of things that make noise and measurements in decibels. Sound energy travels in waves and is measured in frequency and amplitude.Amplitude measures how forceful the wave is.

Noise level is measured in decibels or dBA of sound pressure. 0 dBA is the softest level that a person can hear. Normal speaking voices are around 65 dBA. A rock concert can be about 120 dBA.Sounds that are 85 dBA or above can permanently damage your ears. The more sound pressure, a sound has the less time, it takes to cause damage. For example, a sound at 85 dBA may take as long at 8 hours to cause permanent damage, while a sound at 100 dBA can start damaging hair cells after only 30 minutes of listening. Frequency is measured in the number of sound vibrations in one second. The human ear is sensitive to the sound of frequency in the range of 20 to 2000Hz. Loudness is measured in decibel scale (dB). It is not linear but a logarithmic scale. For example, a change from 40dB to 80 dB represents a 10,000 increase in loudness. In New Delhi, the noise levels range from 28-71 dB at different area at different times, Mumbai 64-102 dB, Rourkela 70-104 dB and Ahmadabad on average is 62 dB.A healthy ear can hear sounds of very low frequency, 20 Hertz (or 20 cycles per second), to a very high frequency of 20,000 Hertz. The lowest a key on the piano is 27 Hertz. The middle C key on a piano creates a 262 Hertz tone. The highest key on the piano is 4186 Hertz.

8.2.1. Sources of Noise Pollution:

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

8.2.1.1. 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.
- **Construction and Renovation:** Construction and renovation work within or near a building can lead to high noise levels. Drilling, hammering, and heavy machinery are typical sources of noise during such activities.
- **Home Entertainment Systems:** Home theaters, gaming consoles, and high-power audio systems can produce loud noise. Watching movies or playing video games with the volume turned up can disturb others in the vicinity.
- **Pets:** Barking dogs, meowing cats, or other noisy pets can be a source of indoor noise pollution. Their sounds can be disruptive, especially in close living quarters.
- **Alarms and Notifications:** Various alarms and notifications, including smoke detectors, security alarms, and electronic device notifications, can create loud, sudden noises, causing discomfort or annoyance.

Impacts of Indoor Noise Pollution:

Indoor noise pollution can have several detrimental effects on individuals and their living or working environments:

1. Health Effects: Prolonged exposure to high indoor noise levels can lead to stress, anxiety, sleep disturbances, and even hearing loss. It can also exacerbate existing health conditions.

2. Reduced Productivity: In work or study environments, noise pollution can reduce productivity, concentration, and cognitive performance.

3. Interpersonal Conflicts: Noise disturbances within shared spaces can lead to conflicts between neighbors or cohabitants.

4. Quality of Life: Noise pollution can significantly impact one's overall quality of life, causing discomfort and affecting mental and emotional well-being.

Mitigation and Prevention:

Efforts can be made to mitigate and prevent indoor noise pollution:

1. Soundproofing: Install soundproofing materials in walls, floors, and ceilings to reduce the transmission of noise between rooms or units.

2. Regular Maintenance: Maintain appliances, HVAC systems, and other equipment to minimize noise generation.

3. Quiet Hours: Establish and adhere to quiet hours in shared living spaces to reduce noise during specific periods.

4. Communication: Open and respectful communication with neighbors or cohabitants can help address noise issues and find compromise.

5. Use of Noise-Canceling Devices: Noise-canceling headphones or white noise machines can help individuals block out unwanted noise.

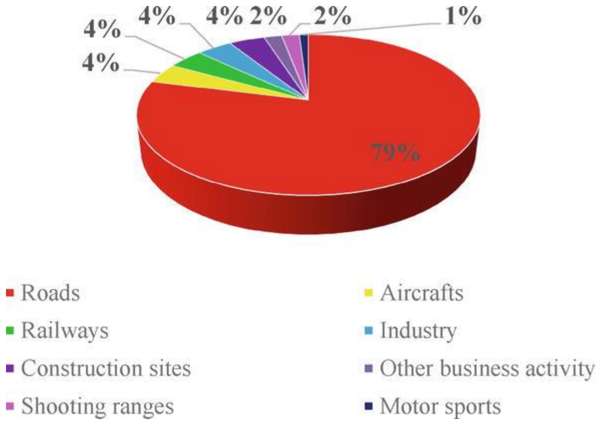
In conclusion, indoor noise pollution arises from various sources within homes, offices, and other indoor environments. Understanding these sources and their impacts is essential for implementing effective strategies to reduce and prevent indoor noise pollution, improving the well-being and quality of life for individuals in these spaces.

8.2.1.2. Outdoor sources of noise

There 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**: The 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 urbanplanning**: 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 machine:** Noise level of as high as 90 dB to 98 dB has been recorded in some farms using heavy types of machinery and equipment. These equipments include 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.

6. Construction and Roadwork*:

Construction activities, roadwork, and infrastructure projects involve heavy machinery, drilling, and other noisy processes. This often leads to elevated noise levels in the vicinity.

7. Commercial Activity:

Commercial establishments, such as restaurants, bars, and shopping centers, can produce noise pollution due to music, conversations, and other activities. Outdoor dining areas and patios can also contribute to noise.

8. Landscape Maintenance:

Lawnmowers, leaf blowers, and other landscaping equipment used by homeowners and professional maintenance crews can generate noise pollution in residential areas.

9. Emergency Services:

Sirens from police cars, ambulances, and fire trucks, while essential for safety, can be sources of loud, sudden noise.

10. Noise from Infrastructure:

Infrastructure elements like bridges, tunnels, and railways can transmit vibrations and noise, affecting nearby communities.

Impacts of Outdoor Noise Pollution:

The impacts of outdoor noise pollution are multifaceted and can have far-reaching consequences:

1. Health Effects: Prolonged exposure to high outdoor noise levels can lead to stress, anxiety, hearing impairment, sleep disturbances, and increased risk of cardiovascular and other health problems.

2. Quality of Life: Outdoor noise pollution can degrade the overall quality of life for residents in affected areas, making outdoor activities less enjoyable and peaceful.

3. Interference with Communication: High noise levels can hinder effective communication, causing difficulties in social interactions and safety.

4. Property Values: Noise pollution can reduce property values, making it challenging to sell or rent homes in noisy areas.

5. Environmental Impact: Wildlife and ecosystems can be negatively impacted by noise pollution, affecting their behavior and reproductive patterns.

Mitigation and Prevention:

Efforts to mitigate and prevent outdoor noise pollution are crucial for creating healthier and more pleasant urban environments:

1. Urban Planning: Implementing zoning regulations that separate noisy areas from residential zones and locating noisy facilities away from population centers can help reduce exposure.

2. Noise Barriers: Erecting noise barriers such as walls or berms along roads and highways can reduce the transmission of traffic noise to adjacent neighborhoods.

3. Quieter Technologies: Encouraging the use of quieter vehicles, construction equipment, and industrial machinery through regulations and incentives can make a significant difference.

4. Soundproofing: Homes, schools, and healthcare facilities can be soundproofed to reduce the intrusion of outdoor noise.

5. Public Awareness: Increasing public awareness about noise pollution and its impacts can lead to more responsible noise behavior.

8.2.2. Types of noise

Noise can be categorized into various types based on its characteristics and sources. Here are some common types of noise and their sources:

a) Environmental noise:

This type of noise originates from various environmental sources, including:

- Traffic noise: Noise generated by vehicles on roads, including cars, motorcycles, trucks, buses, and other modes of transportation.
- Aircraft noise: Noise produced by aircraft during takeoff, landing, and flying overhead.
- Railway noise: Noise generated by trains, including the sound of the locomotive, wheels on the tracks, and train horns.
- Construction noise: Noise generated by construction activities, including heavy machinery, drilling, hammering, and building work.
- Industrial noise: Noise generated by industrial operations and machinery, such as factories, power plants, generators, compressors, and manufacturing processes.

b) Community noise:

This type of noise arises from various community-based sources, including:

- Recreational noise: Noise generated by recreational activities, such as music concerts, festivals, sporting events, and outdoor gatherings.
- Public address systems: Noise generated by the use of loudspeakers, public announcement systems, and amplified sound in public places.
- Commercial noise: Noise from commercial establishments, including restaurants, bars, shops, and entertainment venues.
- Domestic noise: Noise originating from residential areas, such as household appliances, air conditioning units, televisions, radios, and loud conversations.

c) Occupational noise:

This type of noise is specific to workplaces and occupational settings, including:

- Industrial machinery**:** Noise generated by machinery and equipment used in factories, workshops, construction sites, and manufacturing plants.
- Construction sites: Noise generated by construction activities, including drilling, cutting, welding, and operating heavy machinery.
- Power tools: Noise produced by power tools and equipment used in various professions, such as drills, saws, grinders, and pneumatic tools.
- Transportation: Noise generated by vehicles used for transportation purposes, such as trucks, buses, trains, and aircraft, in occupational settings like airports, depots, and logistics hubs.

d) Impulsive noise:

- This type of noise consists of sudden, sharp, and transient sounds, including:
- Explosions: Noise resulting from explosive events, such as fireworks, demolition, or industrial accidents.
- Gunshots: Noise generated by firearms, including handguns, rifles, and shotguns.
- Impact noises: Noise produced by objects colliding or falling, such as hammering, crashes, or falling objects.

e) Electronic noise:

This type of noise is associated with electronic devices and systems, including:

- **Electrical noise**: Interference or unwanted signals in electrical systems, such as humming from transformers or electrical interference in audio equipment.
- **Electronic equipment noise**: Noise generated by electronic devices, such as buzzing from computers, fans, or printers.

These are just a few examples of the types and sources of noise. Noise can vary in intensity, frequency, and duration depending on the specific source and environment. Understanding the sources of noise is essential for implementing effective noise control measures and minimizing the negative impacts of noise pollution.

8.3. Permissible ambient noise pollution

Permissible ambient noise pollution levels vary depending on the location and specific regulations set by the governing bodies in a particular region. The permissible levels are typically determined to protect public health, maintain quality of life, and ensure a safe environment. In many countries, noise pollution regulations are established by local or national authorities. These regulations often set limits for different types of areas, such as residential, commercial, industrial, or quiet zones. The limits are usually measured in decibels (dB) and may vary throughout the day to account for different activities and time periods. For instance, in residential areas, daytime noise limits may range from 55 to 65 dB, while nighttime limits are generally lower, often ranging from 45 to 55 dB. In commercial areas, higher noise levels might be allowed during the day, such as 65 to 75 dB, and lower levels during the night. Industrial areas may have higher limits due to the nature of the activities taking place there. It's important to note that these values are approximate and can differ significantly between regions and countries. Local ordinances and specific circumstances can lead to variations in the permissible ambient noise pollution levels. Therefore, it's always best to refer to the specific regulations applicable to your area to determine the permissible noise levels. If you are concerned about noise pollution in your vicinity, you can contact the local environmental or noise control authorities for information about the permissible limits and any actions that can be taken to address excessive noise.

Effect on communication on living organism

Communication plays a vital role in the lives of living organisms, including humans and various other species. Noise pollution and excessive ambient noise can have significant effects on communication abilities and behaviors. Here are some examples:

Humans: Excessive noise can impair communication among individuals. In social settings, such as workplaces, schools, or public spaces, high levels of noise can make it challenging to understand spoken language, leading to misunderstandings, reduced productivity, and increased stress levels. It can also affect verbal communication between friends, family members, and colleagues, causing frustration and misinterpretation.

Animals: Many animal species rely on acoustic signals for communication, mating, and survival. Noise pollution can disrupt their natural communication processes. For example, birds use songs for mating, territory defense, and warning calls. Excessive noise can interfere with their ability to hear and respond to these signals, leading to reduced reproductive success and increased vulnerability to predation. Similarly, marine animals like whales and dolphins use vocalizations for communication, navigation, and foraging. Underwater noise pollution from human activities, such as shipping, sonar, and seismic surveys, can disrupt their communication and disrupt critical behaviors.

Insects: Insects, such as bees and butterflies, use acoustic signals for communication, particularly during mating and foraging. Noise pollution from sources like traffic, construction, or industrial activities can interfere with their ability to detect and respond to these signals, disrupting their mating behaviors and impacting pollination processes.

Plant-pollinator interactions: Some plants rely on acoustic signals to attract pollinators. Noise pollution can mask or interfere with these signals, making it more challenging for pollinators to locate and interact with flowers. This disruption can have cascading effects on pollination, seed production, and plant reproductive success. Overall, excessive ambient noise pollution can disrupt communication systems and behaviors in various living organisms, leading to negative impacts on their survival, reproduction, and ecological interactions. Efforts to reduce noise pollution and preserve quiet and natural spaces are important for maintaining healthy communication processes in ecosystems.

8.4. Criteria for noise pollution

The criteria for noise pollution are typically based on several factors that help determine whether the noise levels in a particular environment exceed acceptable limits. The criteria commonly used to assess noise pollution include:

Noise level: The noise level is measured in decibels (dB) and serves as a primary criterion for evaluating noise pollution. It indicates the intensity or loudness of the noise. Different areas have specific permissible noise level limits depending on their zoning classification, such as residential, commercial, industrial, or silence zones.

Time of exposure: The duration of exposure to noise is an important factor in assessing its impact. Permissible noise levels may vary based on the time of day. For instance, stricter limits are often imposed during nighttime hours to ensure a quieter environment for rest and sleep.

Frequency spectrum: The frequency spectrum refers to the range of frequencies present in the noise. Different frequencies have varying impacts on human perception and can affect the level of annoyance or disturbance caused by the noise. Some regulations may include specific criteria for certain frequency ranges or evaluate the overall frequency composition of the noise.

Impulsive or continuous noise: Noise can be categorized as either impulsive or continuous. Impulsive noise consists of sudden, sharp sounds with short durations, such as explosions or impacts. Continuous noise refers to a sustained noise level over a period of time. Regulations may have different criteria or limits for impulsive and continuous noise sources.

Sensitivity of the receiving environment: The sensitivity of the receiving environment or area being assessed is taken into account when evaluating noise pollution. Certain locations, such as hospitals, educational institutions, or quiet zones, may have stricter criteria to ensure a peaceful and conducive environment.

Impact on human health: The criteria for noise pollution often consider the potential health effects on humans, including hearing damage, sleep disturbances, stress-related issues, cardiovascular problems, and cognitive impairments. Permissible noise levels are typically determined to protect public health and well-being.

Local regulations and guidelines: Specific regions or countries may have their own local regulations and guidelines for noise pollution. These regulations may provide detailed criteria, measurement methods, and acceptable limits based on local circumstances and considerations.

It's important to note that the criteria for noise pollution may vary depending on the jurisdiction and specific regulations in place. Local authorities and environmental agencies are responsible for enforcing and interpreting the criteria, and they may provide further guidance on assessing and managing noise pollution in their respective areas.

8.5. Noise measurements equipment

Various types of equipment are used for noise measurements to assess and quantify the levels of noise in different environments. Here are some commonly used noise measurement instruments:

Sound-Level Meter (SLM): A sound-level meter is a handheld device used to measure the sound pressure level (SPL) in decibels (dB). It consists of a microphone to capture the sound, an electronic circuit to process the signal, and a display to show the measured SPL. SLMs can provide real-time measurements, as well as average and peak measurements over a specified time period.

Integrating Sound-Level Meter: This type of sound-level meter integrates and averages the sound levels over a specified time period, typically in one-second or one-minute intervals. It provides more accurate measurements by accounting for variations in noise levels over time.

Noise Dosimeter: A noise dosimeter is a portable device worn by an individual to measure and assess personal noise exposure. It is typically used to measure noise exposure over an extended period, such as a full work shift. Dosimeters measure and accumulate noise levels over time and provide metrics such as equivalent continuous sound level (Leq), peak sound level (Lmax), and time-weighted average (TWA) noise exposure.

Octave Band Analyzer: An octave band analyzer measures sound levels in specific frequency bands. It divides the audible frequency range into octave bands, typically ranging from 20 Hz to 20 kHz. This type of analyzer provides information about the distribution of sound energy across different frequency ranges, which is useful for assessing the spectral content of noise.

FFT Analyzer: Fast Fourier Transform (FFT) analyzers are used to analyze and display the frequency content of a sound signal. They provide a graphical representation of the sound spectrum, showing the energy levels at different frequencies. FFT analyzers are often used in more advanced noise measurement applications.

Vibration Meter: In some cases, noise can be associated with vibrations generated by machinery or equipment. A vibration meter measures the vibration levels and provides information about the intensity and frequency content of vibrations. This type of instrument is used to assess and monitor vibration-induced noise.

Data Logging Equipment: Data loggers are devices that record noise levels over an extended period. They can be used in combination with sound-level meters or dosimeters to capture noise data over time. Data logging equipment is helpful for long-term noise monitoring and analysis.

When conducting noise measurements, it is important to use calibrated instruments that comply with relevant standards and regulations. Additionally, the selection of specific equipment depends on the intended purpose of the measurement, the environment being assessed, and the parameters of interest (e.g., sound pressure level, frequency content, personal exposure, etc.).

8.6. Noise permissible limit in India

In India, the permissible noise limits are regulated by the Central Pollution Control Board (CPCB) under the Noise Pollution (Regulation and Control) Rules, 2000. These rules set the maximum permissible noise levels for different areas and time periods. Here are the general permissible noise limits in India:

Industrial Areas:

Daytime (6:00 AM to 10:00 PM): 75 decibels (dB) for industrial areas.

Nighttime (10:00 PM to 6:00 AM): 70 dB for industrial areas.

Commercial Areas:

Daytime: 65 dB for commercial areas.

Nighttime: 55 dB for commercial areas.

Residential Areas:

Daytime: 55 dB for residential areas.

Daytime: 55 dB for residential areas.

Silence Zones:

Daytime: 50 dB for silence zones.

Nighttime: 40 dB for silence zones.

Silence zones include areas that are designated as such by the respective state or local authorities, such as hospitals, educational institutions, courts, and religious places. It's important to note that these are general limits, and some state governments or local authorities may have specific regulations and variations in permissible noise levels. Additionally, certain activities, such as construction or events, may have specific guidelines and permissible noise levels that need to be followed.

If you have specific concerns about noise pollution in a particular location in India, it's advisable to refer to the local regulations and guidelines set by the respective state pollution control boards or municipal authorities.

8.7. Impact of noise pollution on life form and humans

Noise pollution has a significant impact on both humans' health and living organisms such as

a) Health effects on humans:

According to a World Health Organization (WHO) finding, noise is the second largest environmental cause of health problems, just after the impact of air pollution (particulate matter). In addition, we estimate that 22 million people suffer chronic high annoyance, and 6.5 million people suffer chronic high sleep disturbance. As a result of aircraft noise, we estimate that 12,500 school children suffer from reading impairment in school. Prolonged exposure to high levels of noise pollution can lead to various health issues in humans, including:

- **Hearing damage:**Hearing is one of the five senses that human beings have. As such, it is an essential part of the life of any person. But as much as the ear serves the purpose of receiving sound waves, it can also do so to a certain limit. Continuous exposure to loud noise can cause permanent hearing loss or impairment.
- **Stress and sleep disturbances:** Noise pollution can trigger stress responses in the body, leading to elevated levels of stress hormones. This can result in sleep disturbances, fatigue, irritability, and reduced overall well-being. Moreover, being in a noisy place means there is almost no chance of having any sleep. Inadequacy of sleep, in turn, interrupts the normal functioning of the body, leading to discomfort, fatigue, and general moodiness.
- **Cardiovascular problems:**Noise 'excites' the heart. Too much noise means the heart is also disturbed and ends up beating faster, increasing blood pressure. In loud noise, stress hormones such as adrenaline and cortisol are also released. Chronic exposure to noise pollution is associated with increased risks of hypertension, elevated heart rate, heart disease, and stroke. Therefore, blood pressure will definitely increase in noisy environments, thus prompting faster flow of blood, which in turn leads to the secretion of catecholamine, a hormone that further magnifies the number of times the heart pumps blood.

- **Cognitive effects:** Excessive noise can impair concentration, memory, and cognitive performance, particularly in tasks that require focused attention. Because ear is connected to the brain, which coordinates the body's stimulus responses. For this reason, all the sound waves that hit the ear are sent to the brain for interpretation. This means too much noise also gets to the brain, and according to scientific reports, such kind of noise dulls the brain and contributes to a lower response rate by the brain.
- **Mental health issues:** Noise pollution has been linked to increased levels of anxiety, depression, and decreased quality of life.
- **Emotion and Behavioral Change:** This is different from cognitive thinking. Too much noise means disturbance of peace, which may lead to annoyance or anger. People in this state tend to have constant headaches, which may even intensify if the noise is continuous. This may lead to amplified stress levels, and thus, emotions take over, and violence may ensue. This type of behavior is reported to be due to anxiety. With such behavior, it becomes hard to concentrate on work and achieve set goals owing to reduced work efficiency.
- **Reproduction Problems:** Varying studies have been conducted to estimate the effect of noise pollution on reproduction in human beings, and surprisingly, most of these studies have posited that pregnant women exposed to noise pollution during the course of their expectancy tend to give birth to children with less body weight. The stress levels experienced by the expectant mother equally disturbs the unborn child.
- **Trouble Communicating:** High decibel noise can create inconvenience and may not allow two people to communicate clearly. This may lead to misunderstanding, and one may get difficult in understanding the other person

b) Effect of noise pollution on wildlife

Noise pollution can disrupt natural ecosystems and impact various forms of wildlife. It can interfere with feeding, mating, and communication patterns of animals, leading to reduced reproductive success and population declines. For example, birds may change their songs or alter their nesting behavior due to excessive noise, impacting their ability to attract mates and successfully reproduce. Marine animals, such as whales and dolphins, rely on sound for communication, navigation, and foraging. Underwater noise pollution can disrupt their behaviors, leading to disorientation, stress, and potential stranding.

- **Reduction in Feeding Patterns:** Some birds and animals like bats, whales and dolphins use their sharp hearing abilities – known as echolocation for movements, foraging, and avoiding prey. Noise pollution has negated this since the noise monopolizes all the sounds present. As a result, there is increased migration by animals from their natural habitats in search of quieter places where they can feed comfortably. Some animal species have slowly become extinct due to this. They migrate to other ecosystems that are not suitable for them and end up dying.
- **Slow Reaction Time:** Hermit crabs, tortoises and turtles are some of the animals that withdraw to their shells when trouble strikes. The presence of boats or human activity quickly warrants trouble leading to their withdrawal. Noise pollution for long periods of time has distorted this pattern, especially in crabs.
- **Disruption of ecological balance:** Noise pollution can disrupt the balance of ecosystems by altering predator-prey interactions, migration patterns, and foraging behaviors. It can also impact the pollination process, as noise may interfere with the ability of pollinators to locate flowers, affecting plant reproduction and biodiversity.
- **Reduction in Production:** Noise deters the productivity of animals both in the wild and domesticated. Cows produce less milk if there is any noise around them during milking. They get agitated and tend to withdraw the milk due to fear and discomfort. Chickens are also adversely affected by noise. There is a drastic drop in the production of eggs for layers in noisy environments.
- **Behavioral Change:** Like human beings, wild animals also experience a change in behavior depending on the level of peace or noise present. The agitation caused by noise influences heightened aggression levels in all animals, and interestingly, irritation has even been reported for birds. Noise makes them unable to communicate, which may change their behavior into aspects such as cannibalism. Beetles, as another example, are so disturbed by the noise that they end up killing each other.
- **Disturbs Echolocation in Sea Animals:** The marine mammals, Cetaceans (including dolphins), rely on echolocation to communicate, navigate and find partners. They are particularly vulnerable to intensified noise. The excessive noise interfering with echolocation, therefore, disturbs many of their key cognitive behaviors and functions. Sonar devices are a special problem with sound intensity as high as 235 dbs.

- **Death:** Bigger animals are able to survive in noisy areas. The case is different for smaller marine organisms, such as cephalopods – one of the many species of shellfish. These marine fish are heavily affected by the noise coming from moving vessels. The slow movement of large ships over areas where they call habitat can lead to their death. During seismic surveys, compressed air ‘bullets’ are sent deep into the ocean at high speed to search for oil deposits at the bottom of the oceans, resulting in enormous noise in the aquatic environment.
- **Adaptation:** Whereas some of the animals cannot make it in a noisy environment, the rest either die or bear a tough skin through to the end. It is up to the animals to survive in order to ensure the continuation of their species. As such, animals are slowly adapting to life in urban areas. Instead of the usual calling sounds between females and males, animals are using higher pitches to surpass the noise levels.
- **Impacts on overall quality of life:** Noise pollution can diminish the quality of life for both humans and wildlife. It can reduce enjoyment of outdoor spaces, limit recreational activities, and contribute to a general sense of discomfort and annoyance.

To mitigate the negative impacts of noise pollution, efforts should be made to regulate and reduce noise levels, especially in sensitive areas such as residential zones, hospitals, and natural habitats. Implementing noise control measures, promoting sound insulation, and raising awareness about the consequences of noise pollution are important steps towards minimizing its harmful effects on both life forms and humans.

8.8. Control measures of noise pollution in India

In India, noise pollution is regulated and controlled through various measures implemented by the government. Here are some key control measures in place:

Legislation and standards: The primary legislation governing noise pollution in India is the Environment (Protection) Act, 1986, and the Noise Pollution (Regulation and Control) Rules, 2000. These rules set permissible noise levels for different zones and time periods, and establish guidelines for noise-emitting sources such as vehicles, construction activities, industries, and public address systems.

Noise zone classification: The rules classify areas into different zones, including industrial, commercial, residential, and silence zones. Each zone has specific permissible noise limits, with silence zones having the strictest limits to ensure a peaceful environment around places such as hospitals, educational institutions, and courts.

Noise monitoring and enforcement: State Pollution Control Boards (SPCBs) and Pollution Control Committees (PCCs) are responsible for monitoring and enforcing noise pollution regulations. They conduct periodic noise level measurements, undertake inspections, and take actions against violators.

Vehicle noise regulations: The Central Motor Vehicle Rules prescribe noise emission standards for vehicles in India. These standards specify maximum permissible noise levels for different vehicle types and enforce the use of noise control devices such as mufflers and silencers.

Construction site regulations: Construction activities are a significant source of noise pollution. Guidelines have been established to control construction-related noise, including restrictions on working hours, noise barriers, and the use of noise control equipment.

Awareness campaigns and public participation: The government, along with non-governmental organizations, conducts awareness campaigns to educate the public about the harmful effects of noise pollution and the importance of adhering to noise regulations. Public participation is encouraged to report noise pollution violations and contribute to noise control efforts.

Noise pollution control in public places: The use of loudspeakers, public address systems, and amplifiers is regulated to prevent excessive noise levels in public spaces. Time restrictions are imposed, and prior permission is required for conducting public events with amplified sound.

Noise control in industries: Industries are required to comply with noise emission standards and implement noise control measures within their premises. Regular monitoring and enforcement by the concerned authorities help ensure adherence to these regulations.

It is essential for individuals to be aware of their rights and responsibilities regarding noise pollution. They can report violations to the local authorities or seek legal action when necessary. Public cooperation and responsible behavior are crucial in maintaining a noise-controlled environment for the well-being of all.

8.9.Methods of noise pollution control

Noise pollution control involves implementing measures and strategies to minimize or mitigate excessive and unwanted noise in the environment. Here are some methods commonly used to control noise pollution:

- **Source Control:** This method focuses on reducing or eliminating the noise at its source. It involves using quieter machinery and equipment, implementing noise-reducing technologies, and adopting noise control measures during the design and manufacturing processes. Examples include installing mufflers on vehicles and using quieter air conditioning systems.
- **Soundproofing and Insulation:** Soundproofing techniques are employed to reduce the transmission of sound from the source to the surrounding areas. This involves using materials with sound-absorbing properties, such as acoustic panels, insulation, and double-glazed windows. Sound barriers, like walls or fences, can also be constructed to block the direct path of noise.
- **Land-use Planning:** Proper land-use planning helps prevent noise pollution by separating noise-sensitive areas from noisy sources. This involves zoning regulations and urban planning practices that establish buffer zones and restrict the location of noisy industries, airports, highways, and railways near residential areas, schools, and hospitals.
- **Traffic Management:** Managing traffic effectively can significantly reduce noise pollution. Measures include implementing traffic calming techniques like speed limits, roundabouts, and speed bumps to decrease vehicle noise, promoting public transportation to reduce the number of cars on the road, and enforcing regulations on noisy vehicles.
- **Noise Barriers and Enclosures:** Physical barriers, such as walls and fences, can be constructed around noisy sources like construction sites, industrial areas, and highways to prevent sound propagation. Enclosing noisy equipment or machinery within soundproof structures or enclosures can also contain the noise.
- **Education and Awareness:** Raising public awareness about the harmful effects of noise pollution and promoting responsible behavior can contribute to noise reduction. Educating individuals about noise control practices, proper use of machinery, and minimizing noise levels in residential areas can lead to voluntary noise reduction.

- **Legal Regulations:** Governments can establish and enforce noise pollution regulations and standards. These regulations may include permissible noise levels for different types of activities, time restrictions on noisy activities, and penalties for non-compliance. Enforcement agencies can monitor noise levels and take appropriate actions against violators.
- **Noise Monitoring and Assessment:** Regular monitoring of noise levels in various environments helps identify problem areas and evaluate the effectiveness of noise control measures. Monitoring can be done using sound-level meters and other noise measurement devices to ensure compliance with regulations and to inform decision-making.

8.10.Summary

Noise pollution is a pervasive environmental issue that has significant impacts on human health, well-being, and the natural world. It refers to the excessive and unwanted sound that disrupts the balance of the environment and interferes with normal activities. This summary provides an overview of noise pollution, its effects, sources, and potential solutions. Noise pollution has detrimental effects on human health. Prolonged exposure to high noise levels can cause hearing loss, tinnitus, and other auditory disorders. It can also lead to stress, sleep disturbances, cardiovascular problems, impaired cognitive function, and mental health issues such as anxiety and depression. Children are particularly vulnerable to the harmful effects of noise pollution, as it can hinder their learning, concentration, and overall development. Various sources contribute to noise pollution. Environmental noise arises from transportation, including road traffic, aircraft, and railways. Construction activities, industries, and loud events also generate substantial noise. Community noise from recreational activities, commercial establishments, and domestic sources further adds to the problem. Occupational noise in workplaces, such as factories, construction sites, and transportation sectors, poses a risk to workers' health and safety. Noise pollution has adverse effects on wildlife and the natural world. It disrupts the behavior and communication patterns of animals, leading to reduced reproductive success, altered migration routes, and disturbed ecosystems. Marine life, including whales and dolphins, relies on sound for navigation, communication, and feeding, making them particularly vulnerable to underwater noise pollution.

8.11.Termination questions

Q.1. What is the noise pollution and its effects on human health and environment?

Answer: --

Q.2. Discus the permissible ambient noise levels briefly.

Answer: --

Q.3. Write the methods of noise pollution control.

Answer: --

Q.4. Discuss the control measures of noise pollution.

Answer: --

Q.5. Write the noise permissible limit in India.

Answer: --

8.12. Further suggested readings

6. Environmental Science, Subhas Chandra Santra, new central book agency, 3rd Edition, 2011.
7. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.
8. Atmosphere, Weather and Climate, Barry, R. G. 2003, Routledge Press, UK.
9. Ecology: Theories and Applications (4th Edition) by Peter Stiling; Prentice Hall.
10. Biodiversity: a beginner’s guide, John I. Spicer, One world Publications.

Unit-9: Industrial Pollution

Contents

9.1. Introduction

Industrial pollution refers to the release of harmful substances and pollutants into the environment as a result of industrial activities. This can include air, water, and soil pollution caused by manufacturing processes, mining operations, power generation, and other industrial activities. Chemical solvents used in dyeing, metallurgical and tanning,platinum industry play crucial role in water and soil pollution. In addition the burning of fossil fuel is also main component for the air pollution. Industrial pollution can have a significant impact on the environment, human health, and the economy. Air pollution can lead to respiratory diseases, while water pollution can harm aquatic life and contaminate drinking water sources. Soil pollution can also affect agricultural productivity and human health. To mitigate industrial pollution, governments and industry players can implement various measures such as improving production processes, adopting cleaner technologies, and enforcing environmental regulations. Additionally, individuals can also play a role by reducing their consumption and supporting eco-friendly products and practices.

Objectives

- to discuss the different solvent used in industry that cause pollution
- to discuss the warnings fossil fuel and it cause of pollution
- to discuss the heavy metals as pollutants and its sources and biomagnifications

9.2. Chemical solvents used in dyeing

The most common types of solvent dyes are azos (monoazo and bisazo), azo metal complexes, triarylmethane free bases, anthraquinones, acyl cyanines (copper phthalocyanine, aluminum phthalocyanine), and heterocycles. As with organic pigments, solvent dyes come in almost all kinds of structure types. Color performance depends on their chemical structure and their intended application.

It is important to consider the heat resistance of solvent dyes used for the pre-spinning coloring of engineering plastics and chemical fibers. There are solvent dyes that do not meet all of the requirements for sublimation resistance, acid resistance, alkali resistance, solvent resistance, oil resistance, light (weather) resistance, friction resistance, chemical resistance and bright color required by the product after coloring. Solvent dyes are currently available in the following types and varieties.

Blue, green, purple, yellow, orange, and red solvent dyes are produced by Allium. Despite having a slightly lower solubility, anthraquinone solvent dyes are more resistant to light and heat than azo dyes. Therefore, onion dyes play a significant role in plastic coloring. Allium solvent dye is to introduce various substituents into the ring of Allium brewage. The 1-substituent derivatives on the ring of Allium brewage can obtain the solvent dye with red and purple spectrum, especially the hydrogen in the 1-substituent amino group or alkanol amino group of Allium brewage and aromatic amino group, which can form intramolecular hydrogen bond with the group of Allium brewage, which is conducive to the improvement of performance. The important varieties are solvent red 111, etc.

In addition to anthraquinone 1,4-disubstituted solvent dyes of various kinds, huiniang solvent dyes also contain 1,4-diaminoscallion 2,3-disubstituted derivatives. The important varieties are C.I. solvent. The most important varieties of solvent yellow 163 are violet 59, anthraquinone 1.5-disubstituted derivatives, and anthraquinone 1,8-disubstituted derivatives. Heterocyclic solvent dyes are similar to onion dyes in that they come in many varieties. They are bright and have good fastness and fluorescence. Engineering plastics and synthetic fibers are frequently dyed with heterocyclic solvent dyes before spinning. Among them, aminoketone solvent dyes are 1,8-naphthalenic anhydrides and their derivatives or phthalic anhydrides and their derivatives condense with aromatic diamines, which are generated after closed-loop reaction. The chromatography includes yellow, orange and red. Solvent orange 60, Solvent Red 135, Solvent Red 179 and pigment yellow 192 have excellent light and heat resistance, and can be used to color nylon fiber prior to spinning. The solvent dyes of copper phthalide are only limited to yellow, and they have good light and heat resistance. The introduction of substituted alkyls or sulfonates can improve the heat resistance of copper phthalide dyes, which can be used to color polyester before spinning. Among the most important varieties of solvent yellow are solvent yellow 114, solvent yellow 33, and solvent yellow 157.

A solvent dye will dissolve in an organic solvent, and it will impart color to a range of products, including solvents, waxes, plastics, hydrocarbon fuels, and lubricants.The coating and ink industries use solvent-soluble dyes that are insoluble in water. These dyes are used in fuels. Historically, dyes have been used in China for 4000 years, where silkworm breeding is used to extract colors and to dye textiles. One of the earliest dyes was Vat Blue, also known as Indanthrone blue.As synthetic fibers became available in the 1960s, cotton dyes also changed in types and applications. Today, we have azo dye, aromatic dyes, carbonyl dyes, and reactive dyes.

A solvent dye is insoluble in water, but can dissolve in organic solvents. These dyes are used in foil printing, ballpoint pens, paints, lubricants, and waxes, as well as for coloration of solid materials. These dyes are commonly used in pen inks, printing inks, and coatings in the plastics industry. These dyes are also used by biological stain makers to identify cell structures.

In solvent dyes, organic dyes are dissolved in organic solvents, such as alcohols, ethers, ketones, aliphatic hydrocarbons, oils, fats, waxes, and cop tubes. This type of dye can be *dissolved in oils, fats, and aqueous solutions. Apart from printing inks, it is also used in pyrotechnics, lubrication, and plastics.*

Plastics industries use these dyes most frequently. They can color unplasticized polyvinyl chloride, polyester, and nylon. Moreover, they are nonpolar, so they can be used in paint inks, soaps, and other polymers as well. A solvent-based dye is highly soluble in water, so it is easy to work with it. It can also be used for coloring paper, abrasives, and food coloring.

Typically, solvent dyes are soluble in organic solvents. Among other things, they can be used to make neon signs, highlight logos, and create a variety of other colors. Solvent dyes are commonly used for fuel coloring, glass coloring, and marking inks. Throughout the world, solvent dyes are often referred to as CORANTES SOLVENTES. They do not ionize and are nonpolar.

Solvent dyes are commonly used in a wide range of processes since they are soluble in non-polar substances. They can be used for colorants of plastics and wood stains. They can also be used in print inks and pen inks. They can also be used in cell structure staining solutions. Solvent dyes are often available in a wide variety of colors, depending on the application. An example of a solvent dye is a red azo dye.

A solvent dye is an essential finishing tool. It can be used to change the color of a finish and repair a damaged one. It can be added to a variety of solvents, such as wax, paint, or lacquer. You can dilute them with Dye Thiener to create different shades of the same color. For a beautiful finish, you need the right dyes. A good pigment solution in a solvent product is important.

Solvents are versatile, and can be used to dye petrol and hydrocarbon fuels, as well as candles and wood stains. For example, solvents can be used to dye candles and wood stains. They are also commonly used to color plastics and are known as lysochrome dyes. Their durability and ability to withstand high temperatures makes them ideal for dyeing plastic materials and paper. They are also very flexible!

It is a liquid type that is readily soluble in an organic solvent. Insoluble pigments can also damage plastic, so it is important to use dyes in water-based environments. This allows the dye to be easily applied to a surface. Soda based solvents can be easily cleaned with a cloth.

Insoluble pigments can also damage plastic, so it is imperative to use dyes in a water-based environment.

The solvent dyes can be used for many purposes, including coloring acrylic fibers, as well as shading. They are commonly used for wood stains. A wide variety of materials are compatible with these dyes, including paper and textiles. They are water-soluble and can be used as dyes for sculptural objects. The solvent can also be diluted to create custom shades.

Among the most popular acid dyes are azos, which are the salts of complex sulfonic acids. They have a high affinity for cellulosic fibers and are highly reactive dyes. These dyes are not caustic, so they don't form chemical bonds with cellulosic fibers permanently. However, they can be dissolved in a wide range of polar solvents and hydrocarbons.

Applications:

Industrial Use: In the mineral oil, plastics and wax industries, solvent dyes can be used to color products. Solvent dyes are often used in the automotive industry to color gasoline fuels and other hydrocarbon-based fuels. Additionally, they can be used to color candles, waxes, inks and inkjets, wood stains and coatings, and a variety of non-polar, hydrocarbon-based products, such as oils, fats, greases, and a wide variety of hydrocarbon products. In the United States, Solvent Red 164 is primarily used for fuel dyes. Oil Blue 35 is a blue dye used for coloring alcoholic- and hydrocarbon-based solvents, including oils, fats, and waxes. In some countries, it is used as a fuel dye and in some blue smoke formulations. It is also used to color lacquers and inks.

Biological Use:

As a Sudan dye, Sudan III stains triglycerides in frozen sections and some proteins that bind lipids and lipoproteins in paraffin sections. It has red-brown crystals and a maximum absorption at 507 nm.

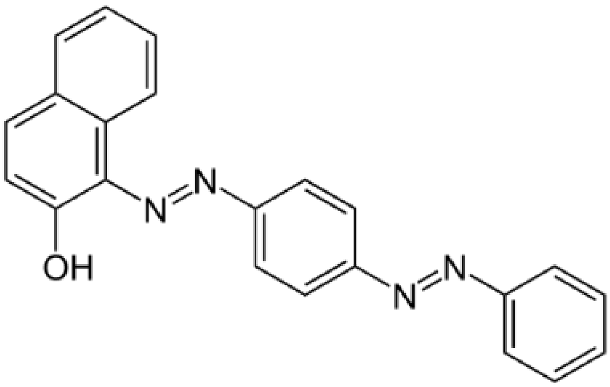


Fig. Sudan III

Polymer Chemistry: Most solvent dyes are used in the plastics industry, where they are used to color a variety of solid materials, including acetates, nylon, polyester, acrylics, PVC, PMMA, PETP, polystyrene and styrene monomers.

Features:

1. Organic solvents dissolve solvent dyes easily. Water does not dissolve them.
2. Solvent dye molecules tend to be non-polar or only mildly polar, which is why they do not ionize.
3. Unlike solid dyes, solvent dyes exhibit light fastness properties, which implies that the color obtained will fade slowly over time.
4. At the end of the manufacturing process, no residues are left behind.
5. When used with organic solvents, they provide good quality and consistency of color to a wide range of products.
6. Due to its excellent thermal resistance, it is corrosion-resistant.

Uses:

1. Typewriter ribbons and copying paper are coated with them in the paper industry. They are also used in inks, ballpoint pens, and printers. Double tone effects are also achieved in printers using them.

2. In the metal industry, they are used for gold imitation on metalized polyester films.

3. In smoke signaling, solvent dyes are used.

4. In the pyrotechnics industry, it is widely used.
5. In the plastic industry, it is used to color nylon acrylics, PMMA, styrene, and PETP.
6. With the help of stains, it is used in medical and scientific research sectors in the biological chain manufacturing segment to identify different cell structure components.
7. Automotive and industrial lubricants are colored with solvent dyes.
8. In the wood industry, solvent dyes are used in wood stains and varnishes.
9. Among the other leading applications of solvent dyes are wax, candles, and cosmetics.

Solvent dyes are used for what? Organic solvents, hydrocarbon fuels, waxes, lubricants, plastics, and other nonpolar materials containing hydrocarbons are colored with solvent dyes.

Which fabrics can be dyed with solvents? Natural fiber dyeing is not suitable for solvent dyeing. It is only suitable for dyeing man-made fibers mainly polyester, nylon and acetate.

How does dye work and what are its types? It is a synthetic dye that is derived from organic or inorganic chemical compounds. Acidic dyes, basic dyes, azoic dyes, nitro dyes, vat dyes, mordant dyes, and sulphur dyes etc.

9.3.Chemical solvents used in tanning

A major problem with tanning is its environmental impact. The main reason is that a large number of chemicals are used at various skin converting stages, including biocides, surfactants, organic solvents, and inorganic substances like toxic chromium (III) salts. For leather goods to be manufactured, it is necessary to apply these chemicals correctly. It involves converting raw skins and hides into leather in order to prevent them from decomposing and prepare them for manufacturing various leather products. It is time-consuming and involves a number of complex chemical and mechanical reactions. One of the stages of tanning involves the use of both natural and synthetic tanning agents. Their mechanism of action depends on their irreversible chemical interactions with collagen, the skin's protein. A tanning procedure prevents the occurrence of ageing processes in collagen fibres, which can cause decomposition of the material. Tanning is the most important stage of raw skin preparation and gives it softness, flexibility, stability, and required qualities.

As tanning processes use a great deal of chemicals and produce a great deal of liquid and solid waste, it is considered to be a "dirty technology". However, it plays an important role in society despite the obvious risks associated with tanning procedures. This market is based on the use of skin and hides, which are by-products of meat production, and their processing into valuable raw materials for the manufacture of a wide range of highly appreciated consumer goods.

Initial skin treatment: A variety of basic chemicals are available in the product range, including hydrochloric acid, sodium hypochlorite, and sodium hydroxide, commonly used in the tanning industry. In the initial stages of the skin processing process, known as wet processing, acid and alkaline solutions are used to prepare the material for tanning. Acid and alkaline solutions are used during soaking, liming, and pickling phases.

Tanning: Inorganic compounds such as aluminum and chromium salts have tanning properties, as do natural substances such as tannins and liver oil. Syntans are alternatives to these components, i.e. synthetic tanning agents that are either used to supplement or replace natural tannins in plant or mineral tanning processes. As a substitute for synthetic preparations with bleaching properties, Rotanina M70 is one of the tanning agents offered by PCC Group. Rotanina W is a syntan used to tan light and medium leather. If used on its own, it softens the leather and gives it a light pink appearance.

Retanning and filling: The Rokryl GA series of acrylic dispersions is a recommended product line for retanning and filling processes. Using these products, leather becomes soft and flexible, giving it a full, pleasing touch even when the raw material has significant structural differences. Additionally, Aldehyde AG, a fur tanning product intended for both separate and combined tanning processes, is included in the offer. Rofill GZA increases the leather's resistance to light and improves its appearance when used in conjunction with synthetic tanning agents and plant tanning agents.

Leather finishing: By increasing the leather's resistance and making it more noble, the finishing processes improve its properties. As the leather is tanned at this stage, Rokryl SW1, which is designed to finish the leather with a smoother surface, is recommended. As an independent product, this product provides a soft, tacky surface with excellent adhesive properties and perfect resistance to flexing. Rokryl SW25M is another item offered, which is able to create a water-resistant film.

Leather treatment involves dyeing, which is influenced by tanning agents, and which is a particularly important stage. In addition to dyeing processes, dispersing and balancing compounds are used. Dyspergator NNOC E is recommended for this stage. It is used as a disperging and equalising agent during the colouring process. Since it has homogeneous dispersion properties, it can be combined with various dyes to achieve uniform leather colour.

Thickening: Thickening is one of the final leather processing stages. It improves the homogeneity of the finishing treatment and enhances the leather's quality. Full grain leather is the main product of this process. In this phase, carefully selected resins are applied, which reduce surface tension and allow the thickening solution to penetrate the leather and wet it. Rokryl SU25 is designed for this application and should be used in combination with Rokpen SU25, which regulates Rokryl penetration depth.

Cleaning and fat removal: In addition to cleaning and degreasing mixtures, PCC Group also offers tanneries and furriesRoksol A87, a preparation used at any stage of tanning to soak leather in water baths. As well as being a component of cleaning and emulsifying household chemicals, Roksol N87, a low-foaming, non-ionic surfactant composition recommended for soaking and degreasing, is also included in the offer. It has good wetting properties and effectively reduces surface tension, thereby accelerating tanning agent penetration.

9.4.Chemical solvents used in metallurgy

The metallurgy must be distinguished from mineralurgy, connected to the mining industry, before it can be defined.

- **Mineralurgy: includes all mechanical, physical, or chemical methods for separating minerals from their gangues and partially purifying them by concentration.**Gravimetry, magnetic separation, and flotation are all methods that allow minerals or metallicparticles to float to the surface of a liquid with the addition of surfactants or solvents. Several compounds are used to optimize the concentration of minerals by modifying their properties.

- **Metallurgy: each of the three main specialties of metallurgy requires a different specialization of the other two. The metallurgy of iron (steel) is divided into precious metals, such as gold, and non-precious metals, such as aluminium. Non-ferrous metals, on the other hand, are divided into precious metals and non-precious metals.**

  As part of metallurgy, metal recycling is done, foundries are constructed (in foundries, mills, and smelters), raw products are manufactured in rolling mills, raw products are processed into semi-finished products, and finally industry equipment and finished goods (automotive, aerospace, information and telecommunications, food packaging, microelectronics, printing, industry, transportation).

Chemical risk

It is common for the metallurgical industry to use a large number of chemicals in its manufacturing processes on a daily basis: paints, solvents, resins, polyurethanes, oils, and mainly for surface treatment (mechanical, chemical, electrochemical or physical operations aimed at changing/improving the appearance, function, or physical characteristics of a material's surface to adapt it to specific conditions of use, such as corrosion protection or improved physical characteristics), and cleaning operations.

Due to the diversity of metals treated, these operations are highly varied, so there are a variety of products (surfactants; complexing agents such as EDTA; acids such as hydrochloric acid, nitric acid, phosphoric acid, sulfuric acid, acetic acid; bases such as sodium and potassium hydroxides, lime; solvents; dyes and waste) and a major chemical hazard.

A few examples

- **Electropolishing:** Among various metals and alloys, electropolishing is a commonly used electrochemical method for smoothing, polishing, deburring and cleaning. Different electrolytes are used in electropolishing processes to remove a fine surface layer electrolytically. These acids are usually mixtures of sulfuric acid, chromic acid, citric acid, and/or phosphoric acid, sometimes with organic compounds as well.
- **Aqueous cleaning:** For aqueous cleaning, the work pieces are placed in a solution that is alkaline or neutral, but may be acidic. It is typically carried out at elevated temperatures (40-90°C) due to its improved cleaning abilities.

- **Pickling:**Prior to other surface treatment processes, pickling is used to brighten and/or remove oxides from metallic surfaces. An acid-based pickling agent is used to chemically react with adhering layers, oxide films, and corrosion products to remove them.
- A mixture of hydrochloric acid (18-22%) and sulphuric acid (25%), or even nitric acid or hydrofluoric acid (20-25%) can also be used in special cases.
- **Fluoride solutions:**In order to pickle certain alloys reliably, fluoride solutions are needed.
- **Anodizing:** Anodizing metals is a process of electrolytic surface oxidation that enhances their natural ability to oxidize; coatings can be 1000 times thicker than the natural layer.
- It is most common for aluminium to be anodised with alumina (Al2O3) formed on its surface. Aluminium is normally anodised in sulphuric acid electrolytes (90% of the time). The anodisation of aluminium can be done in many different types of process solutions: phosphoric acid, sulphuric/oxalic acid, sulphuric/salicylic acid, and chromic acid electrolytes, depending on the application.
- **Phosphating:** Using phosphorous as a chemical agent, phosphating is carried out. Passivation (a state of metals or alloys in which corrosion rate is significantly slowed by the presence of a passive film) can be achieved by treating a surface with a diluted solution of hot phosphoric acid, which in turn improves paint corrosion resistance.
- An artificial passivation is performed on a metal that has been deoxidized (pickled: dissolving unwanted oxides) by an acid (typically sulfuric or hydrochloric acid) or an acid mixture (with nitric acid, or HF).

9.5.Chemical solvents used in platinum industry

Initial treatment includes digestion with aqua regia to produce a solution containing the majority of gold, platinum and palladium as chlorides, leaving behind the more insoluble metals, such as iridium, rhodium, ruthenium, and osmium. Gold is removed from the solution by adding ferrous chloride.

During this stage, the platinum group metals are concentrated more rapidly and the processes are entirely chemical. First, the slime is roasted and leached to remove the last of the copper, nickel, iron, and sulphur. The result is an enriched slime containing approximately 65 percent platinum group metals and gold. Only 130 tons of platinum are mined each year - which is equivalent to only 6% (by weight) of gold mined annually in the Western World - and less than one percent of silver mined annually. To produce one ounce of white gold, approximately 10 tons of ore must be mined. It takes six long months to complete the extraction process. All the platinum ever mined throughout history would fill a basement of less than 25 cubic feet.

In the case of platinum extraction, the feed solution was the raffinate. The potential of the solution was reduced by adding SO_2 before the platinum was extracted from +710 mV to +460 mV. The solution was filtered to remove elemental selenium precipitation during this reduction. Using a phase ratio of 2.4:1, a 40% solution of TBP in 1,2,3-trichloropropane was used to extract the solution in a continuous three-stage countercurrent process. Using a phase ratio of 4.8:1, the loaded organic phase was scrubbed with 5 M HCI in a continuous two-stage counter-current process. In a continuous two-stage counter-current process with a phase ratio of 1.5:1, the scrubbed organic phase was stripped with 0.2 M HCI. After evaporating the strip liquor to one sixth of its original volume, chlorine gas was used to oxidize the platinum to Pt(IV) and NH_4CI solution was added at 80°C to precipitate ammonium chloroplatinate. Afterwards, the platinum salt was filtered off, washed, and ignited to form platinum metal. The metal was assayed and found to have purity greater than 99.99%.

9.6.Burning fossil fuels

Fossil fuels are energy sources derived from crude oil (petroleum), natural gas, and coal that are burned to generate electricity, power transportation (cars and planes), and industrial processes. Our burning of fossil fuels has steadily increased since the invention of coal-fired steam engines in the 1700s. Today, we burn more than four times as much fossil fuels per year as we did in 1776. Climate change and ecosystem changes are a result of the burning of fossil fuels, especially carbon dioxide.

Fossil fuel burning is the primary cause of climate change, altering Earth's ecosystems and harming humans and the environment. Plants on land (which primarily form coal) and plankton in the oceans (which primarily from oil and natural gas) have buried photosynthetic organisms over millions of years to form fossil fuels. By growing these organisms, carbon dioxide was removed from the atmosphere and ocean, and their burial inhibited the movement of carbon into the atmosphere. When fossil fuels are burned, they return carbon dioxide into the atmosphere at a rate hundreds of times faster than they could be buried and much more rapidly than they can be removed by the carbon cycle. In this way, carbon dioxide is released into the atmosphere when fossil fuels are burned, and some of it dissolves in the ocean, resulting in ocean acidification.

As a result of burning fossil fuels, the Earth system is affected in a variety of ways, including:

- It is possible to raise the average air temperature on the planet by releasing greenhouse gases such as carbon dioxide (CO_2) and nitrous oxide (N_2O), which intensify the greenhouse effect (reradiation of heat in the atmosphere). For decades to hundreds of years, these greenhouse gases can remain in the atmosphere.
- A variety of pollutants are released, including sulfur dioxide, nitrogen oxides, and airborne particles such as soot. Poor air quality can lead to respiratory illnesses.
- As a result of the airborne particles, the atmosphere also becomes more reflective, which leads to a slight cooling effect. Airborne particles such as soot and sulfate aerosols (from sulfur dioxide) reflect sunlight back into space, increase cloud formation, and make clouds more reflective. The net effect of burning fossil fuels is warming because the cooling is small compared with the heating caused by the greenhouse effect, in part because airborne particles only remain suspended in the atmosphere for a few days to months, whereas greenhouse gases remain in the atmosphere for decades to hundreds of years.
- Changing patterns of **snow and ice** melt. **Airborne particles** (especially soot) that settle on snow increase the **absorption** of sunlight due to their dark color, heating the surface of the snow causing melting. In certain parts of the world, the presence of soot (in addition to global warming) has caused winter ice and snow melts earlier and faster today than in previous decades, which also changes local patterns of **freshwater availability**.
- Increasing the acidity of **precipitation**.Sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2) react with water vapor, oxygen, and other chemicals to form acid rain. Acid rain can contaminate **freshwater** sources, resulting in harmful algal blooms that reduce **water oxygen levels** and harm fish **populations** and other wildlife. Additionally, acid rain increases chemical **weathering** of rocks, including manmade structures.

- Using large amounts **freshwater**. Power plants that burn fossil fuels cool their systems by removing freshwater from local rivers and lakes. The warm water returned to nearby ecosystems can cause stress for local species.

Pollution by Coal warning

Coal is a major source of energy used globally for electricity generation, heating, and industrial processes. However, the mining, transportation, and combustion of coal can release a range of pollutants into the environment, including greenhouse gases, particulate matter, sulfur dioxide, nitrogen oxides, mercury, and other heavy metals. The combustion of coal releases carbon dioxide, the primary greenhouse gas responsible for global climate change. The particulate matter released during coal combustion can contribute to air pollution, leading to respiratory and cardiovascular diseases. Sulfur dioxide and nitrogen oxides can cause acid rain, which can damage ecosystems and harm human health. Coal mining can also cause environmental damage, including soil erosion, water pollution, and habitat destruction. In addition, the disposal of coal waste, such as fly ash and coal sludge, can lead to water contamination and other environmental hazards. Coal-fired power plants are responsible for a significant portion of the world's air pollution, leading to a range of health problems, such as asthma, bronchitis, heart disease, and lung cancer. Communities living near coal-fired power plants are often disproportionately affected by these health impacts, particularly low-income and minority populations.

Pollution by Oil warning

Oil is a major source of energy used globally for transportation, heating, and industrial processes. However, the extraction, transportation, and combustion of oil can release a range of pollutants into the environment, including greenhouse gases, particulate matter, sulfur dioxide, nitrogen oxides, and other toxic compounds. The combustion of oil releases carbon dioxide, the primary greenhouse gas responsible for global climate change. The particulate matter released during oil combustion can contribute to air pollution, leading to respiratory and cardiovascular diseases. Sulfur dioxide and nitrogen oxides can cause acid rain, which can damage ecosystems and harm human health. Oil spills, which occur during oil transportation or offshore drilling, can have severe and long-lasting effects on marine ecosystems and human health. The chemicals used to clean up oil spills can also be harmful to the environment and human health. Oil extraction, particularly unconventional methods such as fracking, can cause environmental damage, including soil erosion, water pollution, and habitat destruction. The disposal of oil waste, such as drilling mud and produced water, can lead to water contamination and other environmental hazards.

Pollution by Natural gas warning

Natural gas is a fossil fuel that is commonly used for electricity generation, heating, and industrial processes. However, the extraction, transportation, and combustion of natural gas can release a range of pollutants into the environment, including greenhouse gases, particulate matter, nitrogen oxides, sulfur dioxide, and volatile organic compounds. The combustion of natural gas releases carbon dioxide, a greenhouse gas that contributes to global climate change. The combustion of natural gas also releases nitrogen oxides and volatile organic compounds, which can contribute to the formation of ground-level ozone, a major component of smog that can cause respiratory problems. Natural gas production through fracking can cause environmental damage, including soil erosion, water pollution, and habitat destruction. The wastewater produced during natural gas extraction can also contain toxic chemicals that can contaminate water sources and harm human health. The extraction, transportation, and combustion of natural gas can have severe and long-lasting effects on public health, the environment, and the sustainability of affected regions. It is important to transition towards cleaner and more sustainable sources of energy to reduce the impacts of natural gas pollution and mitigate climate change.

Pollution by petroleum warning

Petroleum is a fossil fuel that is widely used for transportation, heating, and industrial processes. However, the extraction, transportation, and combustion of petroleum can release a range of pollutants into the environment, including greenhouse gases, particulate matter, sulfur dioxide, nitrogen oxides, and other toxic compounds. The combustion of petroleum products, such as gasoline and diesel, releases carbon dioxide, the primary greenhouse gas responsible for global climate change. The particulate matter and other pollutants released during combustion can contribute to air pollution, leading to respiratory and cardiovascular diseases. Sulfur dioxide and nitrogen oxides can cause acid rain, which can damage ecosystems and harm human health. Oil spills, which occur during oil transportation or offshore drilling, can have severe and long-lasting effects on marine ecosystems and human health. The chemicals used to clean up oil spills can also be harmful to the environment and human health. Petroleum extraction, particularly through unconventional methods such as fracking, can cause environmental damage, including soil erosion

9.7.Heavy metal pollution

The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentrations. A heavy metal is a metal or metalloid with an atomic density greater than 5 g cm^{-3}, or 5 times or more, than water. In reality, being a heavy metal has less to do with density than it does with chemical properties. Lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), chromium (Cr), copper (Cu), iron (Fe), and platinum group elements are heavy metals. As defined by the International Biological Association, the environment is the combination of external physical conditions that influence and affect the growth, development and survival of organisms. As well as the aquatic, terrestrial, and atmospheric habitats, it includes the flora, fauna, and abiotic. A person's environment is considered in terms of the tangible aspects, such as air, water, and food, as well as the less tangible, but equally important, aspects, the communities in which they live. Any substance in the environment that causes objectionable effects, impairs the welfare of the environment, reduces quality of life, and may lead to death is considered a pollutant. As a result, such a substance must exceed a set or tolerance limit, which can either be desirable or acceptable. As a result, environmental pollution is the presence of a pollutant in the environment; air, water and soil; which may be toxic or poisonous and will harm living things in the polluted environment.

In the earth's crust, many metals are found in traces. Some heavy metals, such as Pb, Hg, Zn, and Cd, are beneficial to plants and animals. You will learn about toxic effects of a few heavy metals in this lesson if excessive levels of heavy metals are introduced into the environment by human activities.

What are heavy metals?

Heavy metals are those with densities greater than 5g cm^{-3}, such as lead, cadmium, mercury, arsenic, selenium, iron, copper, manganese, selenium, zinc, etc. The atomic number of all these metals is greater than 20. There are some metals that are essential to organisms, such as iron, copper, zinc, etc. These are called 'trace metals'. On the other hand, metals such as lead, mercury, cadmium, etc., are toxic to organisms at higher concentrations. Trace metals are those that occur in the earth's crust at less than 1000 parts per million (ppm) or mg/litre.

Sources of Contamination of Environment by Heavy Metals:

There are two ways in which heavy metals enter the environment: naturally or through human activity.

Natural sources: Excessive levels of trace metals may occur in nature due to geographical phenomena such as volcanic eruptions, weathering of rocks, and water leaching into rivers, lakes, and oceans.

Anthropogenic Sources: During mining and uncontrolled smelting of large quantities of metals and ores in open fires, small amounts of heavy metals are released. Metals were extracted from natural resources during the industrial revolution and then processed in industry, where heavy metals were released into the atmosphere. The environment is also affected by heavy metal wastes, including domestic, agricultural and auto exhausts. The following list shows how heavy metals enter the environment through various human activities.

(i) Smelting or processing of ores of metals.

(ii) Mining.

(iii) Burning of fossil fuels such as coal, petrol, kerosene oil.

(iv) Discharging agricultural waste.

(v) Discharging industrial waste.

(vi) Discharging domestic waste.

(vii) Discharge from auto exhausts.

(viii) Using pesticides containing compounds (salts) of heavy metals.

How do Heavy Metals Reach the Ecosystem?

Various toxic inorganic and organic compounds as well as heavy metals are deposited and buried by water, which then carries them to water bodies when they are washed off from the soil. Heavy metal cations are extracted from water that passes through humus, the organic material present in soil (which also makes the soil look green). Humus has a high affinity for heavy metal cations. The roots of crops and other plants absorb these compounds along with water, and they pass on to plants and animals, and then to other plants and animals. In addition to adsorption, heavy metals are also retained in soil by precipitation reactions and adsorption on mineral particles. Typically, heavy metals settle at the bottom of water and sediment accumulates over them, but if organisms consume these, heavy metals enter the food web.

9.8.Heavy metal toxicity

Metal extraction and trading have been around since ancient times, and heavy metals like iron, copper and lead have been of great use throughout history. The growth of the human population, industrialization, increased vehicular traffic, and chemical fertilizers and pesticides have resulted in heavy metal contamination of our environment. In some areas that are close to minerals that occur in nature, heavy metals may also be found in water bodies and underground water. In our country, several villagers in West Bengal are suffering from sores and ulcers due to arsenic poisoning from drinking water. In Minamata, a fishing village in Japan, mercury poisoning hit many villagers. A heavy metal cannot be removed quickly from the environment. A heavy metal cannot be detoxified (made harmless) by organisms using metabolic activity (biochemical reactions within the body). Microorganisms cannot also break down heavy metals into simpler products. Heavy metals are non-biodegradable, so they accumulate in the environment and harm organisms causing heavy metal pollution. The toxicity of heavy metals depends on the type of metal. Metals that are insoluble pass through the body without damaging much. There are metals that cause immediate sickness, making them the most dangerous as they do not give time for treatment. Mercury, for example, is one of the most harmful metals because it **bioaccumulates and* **bio-magnify in the food chain.

**bioaccumulate organisms neutralise some toxins while others are retained in their tissues, known as bioaccumulation.*

** bio-magnify- the concentration of some toxic metals increases with ascending trophic levels throughout the food chain due to biomagnifications. The biomagnifications of foods may make food unsuitable for consumption and cause sickness.

Molecular Basis of Heavy Metals Toxicity

The toxicity of organisms is caused by three general mechanisms, although the effects vary from organism to organism. Metals are strongly attracted to sulfur. Some enzymes in organisms contain sulphydryl groups (S-H). The metal attaches to these groups and blocks the enzyme's active site. As a result, the enzyme is impaired in its normal function. (ii) In the process of synthesis of Biomolecules, heavy metals may displace essential ions. As a result, the biomolecule loses its activity, for example, Pb replaces calcium in bones, causing them to become fragile. (iii) Metal ions may alter enzyme conformation, making them inactive. Toxicity also occurs when the metal blocks the body's defense proteins that fight infections from foreign organisms. Heavy metals can also harm vital organs such as the brain and fetal membranes in pregnant women when they pass through the cell membrane.

9.9.Effects of Pb, Hg and Cd Contamination

Ingesting trace elements for a long period of time or at sufficiently high concentrations can cause some toxic effects. We will examine the sources of contamination and toxic effects of three heavy metals - lead, mercury, and cadmium. Anthropogenic Sources: Human activities have increased the quantity of lead in the environment.

Lead:

Lead is a severe pollutant and is found in the earth's crust in rocks and soil. It occurs naturally in some plants.

Anthropogenic sources: Among the anthropogenic sources are:

i. Soil, which accumulates Pb from mining, smelting, sewage, and agricultural waste;

ii. Vehicle exhausts: Tetraethyl lead is mixed with petrol to improve the efficiency of internal combustion engines. Through automobile exhausts, compounds of Pb are released from fuel evaporating in tanks and carburetters, as well as unburnt fuel from mopeds and motor bikes.

iii. Lead is also released by industries and accumulates in the soil as dust, which eventually reaches the soil. Lead pipes and lead storage tanks contain Pb, which may be carried with water flow. Pipe joints also have Pb in soldering, which may be transported along with waterflow

iv. It is released from lead acid batteries.

v. Paints such as yellow lead chromate, which is used for road markings, deteriorate and enter the environment.
vi. Ceramic glazers use lead compounds for glazing. This forms a source of Pb contamination.

Properties: Some of the characteristics of lead pollutants are discussed below:

(i) Lead and its compounds accumulate in the soil. They also bio-accumulate but do notbiomagnify.

(ii) They are non-biodegradable.

(iii) They remain in the soil and enter food chain when crops take them up.

Entry into human body: Lead has damaging effects on the human system. It can enter the body in the following ways:

i. Lead enters human body from canned food and beverages.
ii. Pb leaches from glazed pottery in acidic media or at high temperatures
iii. Surma used in the eyes also haslead.
iv. Compounds of lead coming out of automobile exhausts enter human through inhalation and skin contact. Children in busy streets show a high lead level in blood.Even breast milk of women living on footpaths have a high lead content.
v. As lead oxides settle in soil, in water, and on fruits and leafy vegetables, they easily enter the food chain and reach the human body.

Toxic effects of Lead: There are several toxic effects of lead, some of which are described below.

i. Lead reaches the bloodstream after entering the human body and through circulation becomes absorbed into soft tissues. Ultimately, lead deposits in bones.
ii. Lead absorption is greater in children and those with calcium deficiency. It can accumulate and remain in the body for many years. During old age and illness, lead moves back from bone to blood to increase the level of lead in blood and become toxic: It can reach the brain and cause brain damage, convulsion and behavioral disorders.
iii. Lead interferes with haemoglobin production and causes anaemia due to deficiency of haemoglobin. Lack of haemoglobin may further damage kidneys and brains.

iv. Lead toxicity may be fatal in acute cases.

Mercury

Inhalation of metallic mercury damages the central nervous system and blood. Mercury is relatively inert and nontoxic.

***Occurrence*:** Besides being present in the earth's crust, mercury is also found in volcanic gases and evaporation from the oceans. Mercury exists as metallic mercury, inorganic salt, and organic methyl mercury. Anaerobic bacteria convert soil bound mercury into dim ethyl mercury. In addition to being present in fossil fuels and minerals, mercury is also present as traces in soil. As mercury is volatile, plants absorb it from soil and release it as mercury vapor during transpiration.

Anthropogenic Sources: There has been mercury in the environment for many centuries, even long before the 20th century. Mercury enters the environment in the following ways:

i. While extracting gold and mercury from ores.

ii. By burning fossil fuels. The mercury content of Indian coal is high. In thermal power plants, mercury escapes as dust particles after escaping from low grade coal, which has a high vapor pressure and combustion temperature.

iii. Mercury is released into the environment by wastes produced by paper, plastic, caustic soda, and chlorine industries.

iv. Mercury compounds are used as pesticides and fungicides because of their toxicity and end up in the environment.

v. In electrical appliances, mercury is used as a conductor of electricity, which is why it is used to make batteries, switches, and lamps. These appliances may release mercury vapours.

Entry of Hg into plants, animals and humans:In plants, mercury is taken up by the roots from the soil. It is also taken up through the leaves through stomata (pores). Because mercury is soluble in fatty acids, which are part of the membranes of all cells in a tissue, it reaches the tissues of animals. Humans receive mercury from the environment through the food chain, mainly through fish consumption. In fish, methyl mercury is the form in which mercury is present.

Toxic effects of Mercury:

As a result of mercury poisoned fish consumption in Japan, people developed a disease called Minamata disease. As a result of mercury poisoning from fish that had died of mercury poisoning, a fishery in Japan in 1953 became contaminated with mercury. The mercury had reached the water as effluent from a vinyl chloride factory. Dead fish had been eaten by fishermen living in Minamata Bay's coastal areas. Their symptoms included weakened muscles, impaired vision, mental retardation, paralysis, and death due to Minamata disease.

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Although mercury is not toxic when swallowed, it causes damage to the nervous system if inhaled in its volatile form. Therefore, mercury should be handled in a well-ventilated environment and cleaned up if it spills. Hg ions have affinity for sulfur and cause harm by binding to sulfur-containing amino acids in proteins. Additionally, hg ions bind to haemoglobin and other blood proteins containing sulphydryl groups.

Most toxic to humans are the organo-mercury compounds especially methyl mercury as it disolves in fatty tissues and bio-accumulates and bio-magnifies. Microorganisms convert high levels of inorganic mercury into the organic derivatives like dimethyl mercury. Methyl mercury compounds are very toxic because of the following reasons:

(i) These compounds can reach the brain and interfere with nerve impulse transmission.

(ii) These compounds can permanently damage the central nervous system of the foetus.

(iii) These compounds also cause increased kidney water loss, which ultimately results in death.

Cadmium: Metals such as cadmium are highly toxic.

Occurrence: Among the natural sources of cadmium are volcanic activity, ocean spray, and forest fires.

Anthropogenic Sources: Humans activity adds more cadmium to atmosphere than natural sources. Coal mining, non-ferrous metal mining, refineries, coal combustion, burning of refuse (water matter) iron and steel industries and phosphate fertilizers are main sources of cadmium. Tobacco containing cadmium is finely dispersed in air when released with cigarette smoke. Cadmium is chemically very similar to zinc. It also occurs with zinc minerals.

Entry of Cadmium into Plants, Animals and Humans: Since cadmium occurs along with zinc in plants that require it, it enters the food chain with it. Cadmium is found in potatoes, wheat, rice, and other grains as well as sea food. Smoking tobacco and chewing tobacco both result in high levels of cadmium in the human system. Tobacco leaves absorb cadmium from irrigation water as well. Cadmium is soluble in water and can reach humans working in zinc mines and smelters that process zinc and electroplate.

Toxic Effects of Cadmium: Cadmium is a cumulative poison. It is retained in the body for a long time and causes

(i) Hypertension (high blood pressure)

(ii) Heart conditions

(iii) Kidney damage

(iv) Red blood cell destruction

(v) Impaired mitochondrial function.

Since Ca^{++} and Cd^{++} share the same charge and are of similar size, it may replace zinc in enzymes, thereby destroying their catalytic functions. There was a bone disease "itaiitai" in Japan where Ca^{++} in bones was replaced with Cd^{++}.

9.10. How to Prevent Heavy Metal Toxicity

To save humans and other organisms from disasters due to toxic effects of heavy metals, prevention measures need to be enforced. In January 1985, the Indian government established a separate Ministry of Environment and Forests to deal with environmental issues. Several non-government agencies have also been busy educating people about the ill effects of metal and other pollution and the ways to prevent it. Industries are asked to take steps to dispose of industrial waste properly. It has been decided to take penal action against industries that do not install proper devices and dump waste in rivers or the soil. Special devices have been designed for the removal of effluents. Newly manufactured cars have been designed to use lead-free petrol. Old cars have been fitted with catalytic converters designed to work on lead-free petrol.

How to Remove Metal Pollution

Despite the fact that metal pollutants are present in very low concentrations, removing them is very difficult. However, there are two ways to design systems for removing metal pollution:

(i) Design one process that removes one metal or

(ii) Design one process that removes several metals.

The following suggestions have been made for rivers and sediments contaminated by heavy metals.

(i) Cover contaminated sediment with layers of uncontaminated, clean soil to prevent rivers from washing away the metal-containing sediment.

(ii) Adding $CaCO_3$ to the sediment to increase pH and to immobilize metals.

(iii) As detoxifying agents, limestone, gypsum, iron sulphate, and activated charcoal can be used.

(iv) Water plants such as pistia and hydrilla can reduce mercury pollution by picking up mercury from water bodies.

What You Have Learnt

- Earth's crust contains traces of heavy metals.
- Their excess in the environment adversely affects living organisms.
- The density of heavy metals is greater than 5 g cm^{-3}.
- At least 1000 ppm of trace metals are present in Earth's crust.
- The accumulation of heavy metals in soil occurs naturally as a result of volcanic activity, weathering of rocks, wind, and water.
- As a result of mining, smelting, fossil fuel burning, discharging agricultural, industrial, and domestic wastes, and auto exhausts, metal pollution is anthropogenic.
- Through the food chain, heavy metals reach ecosystems from soil and water.

- As heavy metals cannot be detoxified or biodegraded, they cannot be rapidly removed from the environment. Some of them, however, bioaccumulation and biomagnify.
- Metals become toxic when they attach to the S-H groups of enzymes or cause conformational changes in them, impairing their proper functioning. Heavy metals can displace essential ions.
- Pb is released by industries, Pb pipes, or leaded petrol. It causes nervous disorders. Through food chains, humans can get methyl mercury, which is especially dangerous. There is a risk of nerve damage and kidney problems as a result. As a result of Hg toxicity, Minamata disease developed in Japan.

9.11. Summery

Industrial pollution is the release of harmful substances into the environment as a result of industrial activities. These substances can include toxic chemicals, greenhouse gases, particulate matter, and other pollutants. Industrial pollution can have severe and long-lasting effects on public health, the environment, and the sustainability of affected regions. The sources of industrial pollution are numerous and include manufacturing processes, power generation, mining, and transportation. The extraction, transportation, and combustion of fossil fuels are a major contributor to industrial pollution, releasing a range of pollutants into the air, water, and soil. Industrial pollution can cause a range of health problems, including respiratory and cardiovascular diseases, cancer, and neurological disorders. The environmental impacts of industrial pollution can include ecosystem damage, habitat destruction, water and soil contamination, and climate change.

9.12. Terminal questions

Q.1: **What is i**ndustrial pollution?

Answer: --

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Q.2: Discuss the different sources of industrial pollution.

Answer: --

--

Q.3: Is chemical solvents are pollutant? Discuss its natures of pollutants.

Answer: ---

Q.4: Discuss the dyeing industry solvents and its causes of water pollution.

Answer: ---

Q.5: Discuss the pollutant material released from metallurgical industry.

Answer: ---

Q.6: What are Burning fossil fuels? Discuss it roles in air, water and soil pollution.

Answer: ---

9.13. Further suggested readings

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Block-4

PGEVS-102N

Environmental Chemistry

Rajarshi Tandon Open University, Prayagraj

Block- 4

Instrumental Techniques and of Pollution Control

UNIT -10
Radioactive and Thermal Pollution

UNIT-11
Instrumental Techniques

UNIT-12
Air prevention and Control of pollution

PGEVS-102N

Rajarshi Tandon Open
University, Prayagraj

Environmental Chemistry

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Introduction

This fourth block of environmental chemistry consists of following three units:

Unit-10: This unit covers the radioactive and thermal pollution, the nuclear power plants based waste material such as radioactive waste, biological and chemicals release from war are also discussed.

Unit-11: This unit covers principle and application of atomic absorption spectrophotometer (AAS), inductive couple plasma emission spectroscopy (ICPES), x-ray fluorescence, fourier transforms infrared spectroscopy (FTIR), ion selective electrode for air, water and soil sample analysis.

Unit-12: This unit covers the air (prevention & control of pollution) act 1981 as amended by amendment 1987 & rule 1982, motor vehicle act, 1988, the environment (protection) act 1986, rules 1986, and the national green tribunal act 2010.

Unit-10: Radioactive and Thermal Pollution

Contents

10.1. Introduction

Radioactive pollution is the release of high-energy particles or radiation into the environment. This type of pollution can occur naturally, such as from cosmic radiation, or from human-made sources, such as nuclear power plants, nuclear weapons testing, and medical procedures that use radioactive materials. The health effects of radioactive pollution depend on the type and amount of radiation exposure, as well as the duration of exposure. Exposure to high levels of radiation can cause acute health effects, such as radiation sickness and even death, while long-term exposure to lower levels of radiation can increase the risk of cancer and other chronic diseases. Thermal pollution, on the other hand, is the release of heated water or air into the environment, typically from industrial processes or power plants. This can cause changes in the temperature of bodies of water, which can negatively impact aquatic ecosystems and the organisms that rely on them. The effects of thermal pollution can include reduced oxygen levels in the water, changes in the timing of biological events, and the displacement or extinction of certain species. In addition, thermal pollution can also affect human health, particularly in areas where water is used for drinking or recreation.

Objectives

- To discuss the nuclear power plants-based waste material
- To discuss the wet solid wastes and liquid wastes
- To discuss the biological and chemical waste release during war
- To discuss thermal pollution and its effects on environment

10.2. Nuclear power plants-based waste material

As a result of nuclear fuel cycle activities, radioactive waste is generated. The management of radiation-emitting radioactive material is an issue that distinguishes nuclear wastes from other wastes. In order for nuclear energy to be accepted by the public, the waste management of radioactive wastes must be assured as safe. **As compared to other toxic industrial wastes, nuclear wastes are not all particularly hazardous or difficult to manage.**

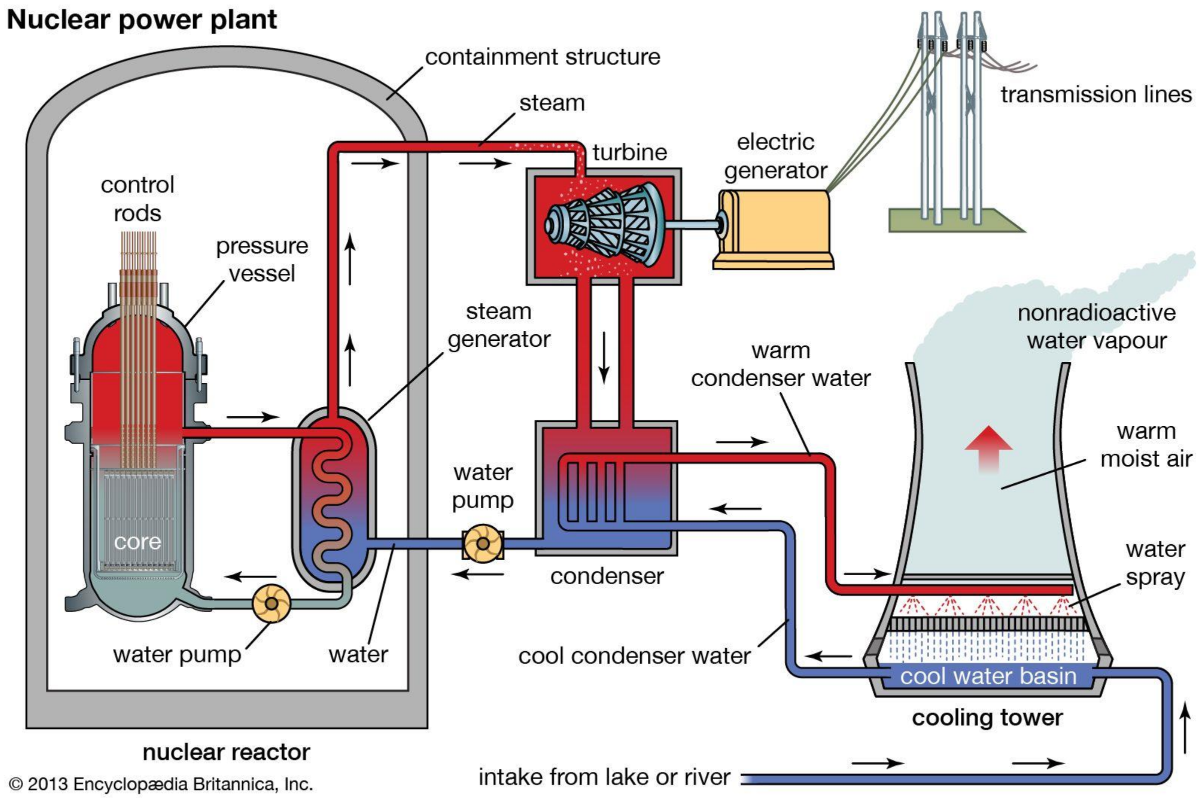

Fig.10.1: Nuclear Power Plant Diagram

It has always been our goal to manage radioactive waste safely since the beginning of our nuclear energy program. For waste management systems, a coherent comprehensive and consistent set of principles and standards is being followed throughout the world in accordance with international guidelines. In order to avoid any unnecessary radiation risks to workers, the public (both present and future generations), and the environment, radioactive waste would be managed.

In order to manage these wastes, a variety of activities must be performed, including handling, treating, conditioning, transporting, storing and disposing of them. The recent technological developments in India realize the recovery of valuable radionuclides from radioactive waste for societal application as well as ensuring the highest level of safety in the management of radioactive waste.

Among the most important components of the national energy system are nuclear power plants. The use of nuclear power in conjunction with other forms of energy contributes to the security of national electricity supplies. Nuclear power is economically competitive and environmentally friendly compared to most other forms of energy used in electricity production. The contribution of nuclear energy to national energy supplies in the medium term and beyond seems inevitable if the standards of living in industrialized countries of the world are to be maintained and the energy needs of developing countries are to be met. When nuclear reactors are operated, some radioactive waste is produced.

It is important to note, however, that these wastes have a much smaller volume than coal-fired electrical generators'. Generally, nuclear power plants generate wastes with low activity and radionuclides with a short half-life and low radiotoxicity. In spite of this, nuclear power plants produce the greatest volume of radioactive wastes and are the most numerous nuclear facilities. Based on the type of reactor, its specific design features, its operating conditions, and the integrity of the fuel, nuclear power plants produce a variety of wastes.

From structural, moderator, and coolant materials, these radioactive wastes include activated radionuclide’s, corrosion products, and fuel-borne fission products. In nuclear power plants, methods for treatment and conditioning of waste are now highly effective and reliable, and are being further developed to improve the whole waste management system's safety and economy.

Wastes generated at nuclear power plants

At nuclear power plants, low- and intermediate-level radioactive waste (LILW) occurs when various materials are contaminated with radionuclide’s generated during fission and activation or released from fuel or cladding surfaces. In addition to the reactor coolant system, spent fuel storage pools also contain radionuclide’s that are released and collected.

During refueling or maintenance of a nuclear power plant, the main waste is the removal of components (mainly activated solids, like stainless steel containing cobalt-60 and nickel-63) or operational wastes, including radioactive liquids, filters, and ion-exchange resins contaminated by fission products from liquid coolant circuits. For the purpose of reducing interim storage volumes of waste and minimizing disposal costs, all countries are taking or intending to take measures to reduce waste arisings as much as possible.

Fig.10.2: Wastes Generated at Nuclear Power Plants

The reduction of volume is particularly attractive in the case of low-level waste, which has a large volume but low radiation activity. There can be significant improvements made through administrative measures, e.g. replacing paper towels with hot air driers, introducing reusable long lasting protective clothing, etc., and through general improvements in "housekeeping".

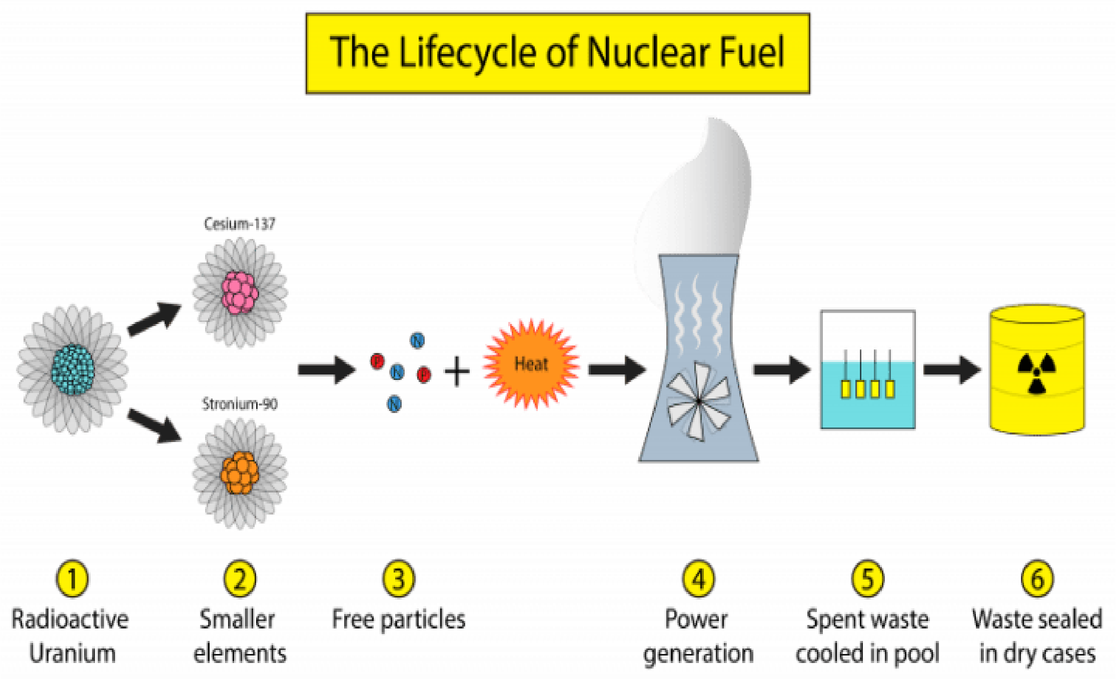

Fig.10.3: Wastes Generated at Nuclear Power Plants

They are essentially of two types-

Primary Wastes comprising radioactively contaminated equipment (metallic hardware) spent radiation sources etc.

Secondary wastes resulting from various operational activities, such as protective rubber and plastic wears, cellulosic and fibrous material, organic ion exchange resins, filter cartridges, and others.

10.3. WET SOLID WASTES AND LIQUID WASTES

Solid Waste

Different nuclear installations generate substantial amounts of radioactive solid waste from LILs (Low and Intermediate Level Waste (LILW)) of different nature. Solid wastes are treated and conditioned, in order to minimize the mobility of the radioactive materials contained in them. With mature industrial operations involving multiple interrelated steps and diverse technologies, a wide range of treatment and conditioning processes are available today.

In order to protect the health and safety of the public as well as the quality of the environment, including air, soil, and water, proper disposal of solid waste is essential. As a result of radioactive decay, radiological hazards associated with short-lived wastes are significantly reduced over a few hundred years. Near Surface Disposal Facility (NSDF) facilities dispose of waste in specially constructed engineering modules such as concrete trenches, stone lined trenches, and tile holes. A multi barrier principle ensures effective containment and isolation of radioactivity until it decays to an innocuous level in these disposal structures, which are located above and underground in access-controlled areas. By monitoring underground soil and water samples regularly to confirm effective confinement of radioactivity present in the disposed waste, bore-wells laid out in a planned manner are used to monitor the NSDFs where the disposal structures are located.

The high level solid wastes contain large concentrations of both short and long lived radionuclide, which warrants high degree of isolation from the biosphere and typically calls for final disposal in Geological Disposal Facilities (GDFs). It was believed that long-term disposal would be achieved best by identifying suitable sites where waste could be buried, known as deep geological disposal.

Liquid Waste

In order to immobilize liquid waste streams, various pre-treatment techniques are used such as filtration, adsorption, chemical treatment, evaporation, ion exchange, reverse osmosis, etc.

Around the world, a variety of reactors are now operating commercially, generating a variety of waste streams. Water-cooled and moderated reactors generate more liquid waste than gas-cooled reactors, so these streams differ both in activity content and in liquid waste generation. Compared to pressurized water reactors (PWRs), boiling-water reactors (BWRs) generate a significant amount of liquid waste. Since heavy water is recycled through once-through ion exchange techniques in heavy-water reactors (HWRs), no liquid concentrates are produced.

Additionally to primary coolant cleanups (PWR and BWR), active liquid wastes are generated by drains, wash water, leakage waters, and spent fuel storage pond cleanups. In addition to creating liquid wastes during decontamination operations, reactor equipment and piping maintenance creates liquid wastes. Among the wastes generated by nuclear power plants are crud (corrosion products) and organics, such as oxalic acid and citric acid. Wet solids, on the other hand, include spent ion-exchange resins, filter media, and sludges. Wet solid waste generated from power reactors is largely composed of spent resins.

Deep demineralizers and nuclear power plants use beads resin as bead resin. In PWRs, powdered resins are rarely used, but they are commonly used in BWRs with pre-coated filter demineralizers. In many BWRs, powdered resin wastes are primarily generated by the "condensate polishers" that are used to clean condensed water after liquid wastes have been evaporated. As part of the liquid waste processing process at nuclear power plants, pre-coated filters produce wet solid waste filters. As a result of the filter aids- usually diatomaceous earth or cellulose fibres- and the crud removed from the liquid waste, filter sludges are formed. Some filtration systems do not require filter aids. Therefore, such sludges do not contain any other substances.

Gaseous waste and radioactive aerosols

To effectively treat gaseous waste, various techniques are employed, including adsorption on activated charcoal, absorption / scrubbing, filtration by high-efficiency particulate air filters, etc.

A nuclear power plant generates some airborne radioactive wastes either as particulates or as gaseous aerosols in its normal operation. There are several particle sizes that can be generated as particulate radioactive aerosols, possibly in combination with non-radioactive aerosols. As a result of activated corrosion products and fission products, radioactive decay of gases leads to in volatile elements, and adsorption of volatile radionuclides in suspended material are the three main sources of aerosols.

Halogens, noble gases, tritium, and carbon-14 are the most important volatile radionuclides, which contribute to gaseous radioactive waste generated during normal nuclear power plant operation. The composition and the amount of radioactivity present in the various airborne waste streams are largely determined by the reactor type and the release pathway. Before discharge to the atmosphere, all gaseous effluents from nuclear power plants undergo treatment to remove the majority of radioactive components.

Management of Nuclear Waste:

In spite of their small size, wastes generated by nuclear reactors or other industrial activities utilizing radioactive materials require appropriate management despite their small volume. During reprocessing operations, a variety of secondary streams are generated, some of which are products, while many of them are wastes. From the beginning of India's nuclear energy programme, safe management of nuclear waste has been a high priority to ensure the safety of the environment, human health, and future generations. The prevalent philosophy has been to isolate nuclear wastes after suitable conditioning in an inert matrix to mitigate dispersal concerns. There has also been an increased appreciation recently that nuclear waste can be used to extract various radionuclides’ that are useful to society in a number of ways. Because of this, nuclear waste has been viewed as wealth, a view that has been vindicated by the development of selective extract ants, advanced separation techniques, and remote handling equipments to ensure radionuclide’s like ^{137}Cesium, ^{90}Stronium, and ^{106}Ruthenium can be recovered.

When nuclear fuel cycle facilities are operated and maintained, they generate nuclear waste in the form of gaseous, liquid, and solids. Gaseous waste is treated at the source of generation using the techniques of absorption-chemical scrubbing, adsorption on activated charcoal, and particulate air filtering. It is possible to treat liquid waste streams in a variety of ways, such as filtration, adsorption, chemical treatment, evaporation, ion exchange, reverse osmosis, etc. Further research aims to develop the technology for achieving 'Near Zero Discharge' of radioactivity to the environment, depending on the nature and volume of the waste streams. To ensure effective containment of radioactive solid waste until it decays to an innocuous level, radioactive solid waste is segregated and volume reduced before it is disposed in specially constructed engineered structures such as stone lined trenches, reinforced concrete trenches and tile holes. By incorporating new technologies such as high pressure compaction, plasma-based incineration systems, etc., recent developments have aimed to minimize waste volume. In addition, efforts are being made to develop disposal modules with effective containment and space utilization.

Vitrification of HLLW is a complex process and poses challenges in view of high temperature operations in presence of high amount of radioactivity. As a result very few countries in world could master the technology of vitrification of HLLW and India is among them. Three melter technologies, Induction Heated Metallic Melter (IHMM), Joule Heated Ceramic Melter (JHCM) and Cold Crucible Induction Melter (CCIM), have been indigenously developed for vitrification of HLLW. HLLW vitrification plants, based on IHMM or JHCM technologies, have been constructed and successfully operated at Trombay, Tarapur and Kalpakkam sites of India.

Vitrification Cell (IHMM), WIP, Trombay Joule Heated Ceramic Melter, Tarapur Inside view of Cold Crucible Induction Melter R&D in the field of partitioning of Minor Actinides from HLLW are also aimed to separate out the long - lived radioactive waste constituents prior to immobilizing then in glass matrice. The long lived radio-contaminants is planned to be burnt in fast reactors or Accelerator Driven Sub Critical systems to get converted into short- lived species. This will reduce the need of long term isolation of radionuclide from environment by multifold. R&D is also directed towards management of Hulls, contaminated leftover pieces of zirconium clad tube after dissolution of fuel, and Geological Disposal Facility for safe disposal of vitrified HLLW and long lived waste with objective to long term isolation of radionuclide from the human environment.

10.4. Radioactive waste

Radioactive waste is a hazardous waste that contains radioactive material. Radioactive waste is an outcome of many activities, including nuclear research, nuclear medicine, nuclear power generation, rare-earth mining, and nuclear weapons reclaiming. Government agencies regulate the storage and disposal of radioactive waste in order to protect human health and environment.

Radioactive waste is classified into low-level waste (LLW), intermediate- level waste (ILW) and high-level waste (HLW). low- level waste ,such as paper, tools,rags, clothing, these things contain slight amount of mostly short-lived radioactivity, intermediate-level waste (ILW), which contains large amounts of radioactivity and requires some shielding, and high-level waste (HLW), which is highly radioactive and blazing due to decay heat, so requires cooling and shielding.

About 96% of spent nuclear fuel is recycled back into Uranium-based and mixed- oxide fuels in nuclear reprocessing plants.The remaining 4% is minor actinides and fission products the latter of which are a mixture of stable and quickly decaying (most likely already having decayed in the spent fuel pool) elements, such as Strontium-90 and Caesium-137 are medium lived fission product and finally seven long-lived fission products with half lives in the hundreds of thousands to millions of years. The minor actinides till then are heavy elements other than neutron capture that created the uranium and plutonium. Their half lives range from years to millions of years and as alpha emitters they are commonly radiotoxic. Although there are proposed - and to a much minor extent current - uses of all those elements, marketable scale reprocessing using the PUREX-process disposes of them as waste together with the fission products. The waste is thereafter converted into a glass-like ceramic for storage in a deep geological repository.

The storage time of radioactive waste must depend on the type of waste and radioactive isotopes it contains. Segregation and storage on the surface or near surface have been short term approaches to radioactive waste storage. Burial in a deep geological depository is a blessed solution for long-term storage of high-level waste, although reuse and transformation are favored solutions for decreasing the HLW inventory. If chemical separation processes cannot achieve a very high purity then spent nuclear fuel recycling boundaries are regulatory and economic as well as the issue of radioactive contamination. Besides, elements may be present in both favorable and problematic isotopes, which would require pricey and energy demanding isotope splitting for their use, at present it is an uneconomic possibility.

An overview of the amounts of radioactive waste and management approaches for most developed countries is presented and The International Atomic Energy Agency (IAEA)'s Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management as part of the joint reviews periodically.

Sources of Radioactive waste:

Radioactive waste comes from many different sources. In countries with nuclear power plants, nuclear fuel treatment plants, or nuclear armament, the larger part of waste originates from the nuclear weapons reprocessing and nuclear fuel cycle. Other sources include industrial wastes and medical wastes, as well as naturally occurring radioactive materials (NORM) that can be concentrated as a consequence of the processing or consumption of coal, gas, and oil, and some minerals, as discussed below.

Front end

The nuclear fuel cycle front end waste is usually alpha-emitting waste from the extraction of uranium. It repeatedly contains radium and its decay products.

Uranium dioxide (UO2) intensified from mining is a thousand or eventually as radioactive as the granite used in buildings. It is purified from yellowcake (U3O8), and then converted to uranium hexafluoride gas (UF6). As a gas, it witnesses enrichment to increase the U-235 content from 0.7% to about 4.4% (LEU). It is then converted into a hard ceramic oxide (UO2) for gathering as reactor fuel elements.

The main by-product of enhancement is depleted uranium (DU), basically the U-238 isotope, with a U-235 essence of ~0.3%. It is reserved, either as UF6 or as U3O8. Some are used in applications where its excessively high density makes it invaluable such as anti-tank shells, and at least one event even a sailboat keel. It is also used with plutonium for making mixed oxide fuel (MOX) and to dilute, or downblend, highly heighten uranium from weapons stockpiles which is now being sidetracked to become reactor fuel.

Back end

In the nuclear fuel cycle back end mostly spent fuel rods, taken fission products that emit gamma and beta radiation, and actinides that emit alpha particles, such as uranium-234 (half-life 245 thousand years), neptunium-237 (2.144 million years), plutonium-238 (87.7 years) and americium-241 (432 years), and even many times some neutron emitters like as californium (half-life of 898 years for californium-251). Nuclear reactors form these isotopes.

Types of Radioactive waste:

It is important to discriminate the processing of uranium to make fuel from the process again of used fuel. Used fuel takes the extremely radioactive products of fission. Many of these are neutron buffers, called neutron poisons in this situation. These ultimately build up to a level where they absorb so many neutrons that the chain reaction stops, despite the control rods completely removed. At that point, the fuel has to be replaced in the reactor with fresh fuel, even though there is still a significant quantity of uranium-235 and plutonium on offer. In the United States, this used fuel is usually "stored", although in other countries like Russia, the United Kingdom, Japan, France and India, the fuel is reprocessed to remove the fission products, and the fuel then be reutilized. The fission products discarded from the fuel are a consolidated form of high-level waste as are the chemicals used in the procedure. Although most countries reprocess the fuel carrying out single plutonium cycles, India is planning numerous plutonium recycling schemes and Russia follows a closed cycle.

Radioactive waste includes any material that is either intrinsically radioactive, or has been contaminated by radioactivity, and that is deemed to have no further use. Government policy dictates whether certain materials such as used nuclear fuel and plutonium are categorized as waste. Every radionuclide has a half-life: the time taken for half of its atoms to decay, and thus for it to lose half of its radioactivity. Radionuclides with long half-lives tend to be alpha and beta emitters making their handling easier while those with short half-lives tend to emit the more penetrating gamma rays. Eventually all radioactive waste decays into non-radioactive elements. The more radioactive an isotope is, the faster it decays. Radioactive waste is typically classified as either low-level (LLW), intermediate-level (ILW), or high-level (HLW), dependent, primarily, on its level of radioactivity.

Low-level Waste:

Low-level Waste (LLW) has a radioactive content not exceeding four gigabecquerels per tonne (GBq/t) of alpha activity or 12 GBq/t beta-gamma activity. LLW does not require shielding during handling and transport, and is suitable for disposal in near surface facilities.LLW is generated from hospitals and industry, as well as the nuclear fuel cycle. It comprises paper, rags, tools, clothing, filters, etc., which contain small amounts of mostly short-lived radioactivity. To reduce its volume, LLW is often compacted or incinerated before disposal. LLW comprises some 90% of the volume but only 1% of the radioactivity of all radioactive waste.

Intermediate-level waste:

Intermediate-level waste (ILW) is more radioactive than LLW, but the heat it generates (<2 kW/m3) is not sufficient to be taken into account in the design or selection of storage and disposal facilities. Due to its higher levels of radioactivity, ILW requires some shielding.ILW typically comprises resins, chemical sludges, and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal. It makes up some 7% of the volume and has 4% of the radioactivity of all radioactive waste.

High-level waste:

High-level waste (HLW) is sufficiently radioactive for its decay heat (>2kW/m3) to increase its temperature, and the temperature of its surroundings, significantly. As a result, HLW requires cooling and shielding.HLW arises from the 'burning' of uranium fuel in a nuclear reactor. HLW contains the fission products and transuranic elements generated in the reactor core. HLW accounts for just 3% of the volume, but 95% of the total radioactivity of produced waste. There are two distinct kinds of HLW:

- Used fuel that has been designated as waste.
- Separated waste from reprocessing of used fuel.

HLW has both long-lived and short-lived components, depending on the length of time it will take for the radioactivity of particular radionuclides to decrease to levels that are considered non-hazardous for people and the surrounding environment. If generally short-lived fission products can be separated from long-lived actinides, this distinction becomes important in management and disposal of HLW. HLW is the focus of significant attention regarding nuclear power, and is managed accordingly.

Very low-level waste:

Exempt waste and very low-level waste (VLLW) contains radioactive materials at a level which is not considered harmful to people or the surrounding environment. It consists mainly of demolished material (such as concrete, plaster, bricks, metal, valves, piping, etc.) produced during rehabilitation or dismantling operations on nuclear industrial sites. Other industries, such as food processing, chemical, steel, etc., also produce VLLW as a result of the concentration of natural radioactivity present in certain minerals used in their manufacturing processes (see also information page on Naturally-Occurring Radioactive Materials). The waste is therefore disposed of with domestic refuse, although countries such as France are currently developing specifically designed VLLW disposal facilities.

Effects of radioactive waste:

Exposure to large amounts of radioactivity can cause nausea, vomiting, hair loss, and diarrhea, and hemorrhage, destruction of the intestinal lining, central nervous system damage, and death. It also causes DNA damage and raises the risk of cancer, particularly in young children and fetuses. Below are the three radioactive substances health experts are most concerned about, the detected levels in Japan, and what they mean for human health:

IODINE-131:

Leafy green vegetables in Japan were found this week to contain up to 22,000 becquerels of iodine-131 for every kilogram. Such a level exceeds the limit set by the European Union by 11 times. Becquerel is a measure of radioactivity. Eating a kilogram (slightly more than two pounds) of such vegetables would give half the amount of radiation typically received by the average person from the natural environment in a year.

Eating this amount every day for 45 days will accumulate 50 millisieverts, the annual radiation limit set for a nuclear plant worker. Millisievert quantifies the amount of radiation absorbed by human tissues. Exposure to 100 millisieverts a year increases the risk of cancer. That is equivalent to about three whole body CT scans. If inhaled or swallowed, iodine-131 concentrates in the thyroid gland and increases the risk of thyroid cancer. Children, fetuses and young adults are especially vulnerable. The risk of thyroid cancer can be lowered by taking potassium iodide pills, which helps prevent the uptake of the radioactive iodine.

However, iodine-131 disintegrates relatively quickly and its radioactivity is halved every 8 days. This means it loses all its harmfulness in 80 days.

10.5. Biological waste release from war

Biological waste release from war can have severe and long-lasting effects on the environment and public health. Biological waste can include a range of hazardous materials, including chemical weapons, biological agents, and radioactive materials. Chemical weapons, such as nerve agents and blister agents, can contaminate soil, water, and air, causing acute and chronic health effects in humans and animals. Exposure to these chemicals can cause skin burns, respiratory problems, and even death. Biological agents, such as anthrax, can also have severe health consequences, including flu-like symptoms, respiratory failure, and death. These agents can spread rapidly through the environment, infecting humans and animals alike. Radioactive materials, such as depleted uranium and other radioactive isotopes, can also contaminate the environment, causing long-term health effects such as cancer, birth defects, and genetic mutations. The release of biological waste from war can also have ecological consequences. It can cause changes in the composition of ecosystems, leading to the decline or extinction of species. It can also contaminate soil and water, making it unsuitable for agriculture or other human uses. Some of the biological agents that may be released during war include:

- Anthrax, a bacterial agent that can cause flu-like symptoms, respiratory failure, and death.
- Smallpox, a viral agent that can cause severe and often fatal disease.
- Plague, a bacterial agent that can cause fever, coughing, and respiratory failure.
- Botulinum toxin, a bacterial agent that can cause muscle paralysis and respiratory failure.
- Ricin, a plant-derived toxin that can cause respiratory and circulatory failure.
- Brucellosis, a bacterial agent that can cause fever, chills, and joint pain.
- Tularemia, a bacterial agent that can cause fever, swollen lymph nodes, and pneumonia etc.

10.6. Chemicals waste release from war

Chemical waste released during war can have serious and long-lasting environmental and health consequences. When weapons and munitions are used during a war, they can release a variety of hazardous chemicals into the environment, such as heavy metals, solvents, pesticides, and nerve agents. These chemicals can contaminate soil, water, and air, and can persist in the environment for years or even decades. They can also bioaccumulation in the food chain, potentially leading to health problems for humans and wildlife.

In addition to direct releases from weapons and munitions, war can also lead to other forms of chemical waste, such as from military bases, industrial facilities, and infrastructure damage. This can include fuels, lubricants, batteries, and other hazardous chemicals that are commonly used in military operations. Overall, the release of chemical waste during war can have significant environmental and health impacts, and it is important to take steps to prevent and mitigate these releases as much as possible. Some of the chemicals that may be released during war include:

- Nerve agents, such as Sarin and VX, which can cause respiratory failure, seizures, and death.
- Mustard gas, which can cause severe skin burns, respiratory problems, and even death.
- Chlorine gas, which can cause severe respiratory problems, such as lung edema and bronchitis.
- Sulfur dioxide and nitrogen oxides, which can cause acid rain and damage to crops, forests, and aquatic ecosystems.
- Heavy metals, such as lead, mercury, and cadmium, which can accumulate in the environment and cause long-term health effects such as neurological damage, cancer, and birth defects.
- Radioactive isotopes, such as uranium and plutonium, which can cause radiation sickness, cancer, and genetic mutations.
- PCBs (polychlorinated biphenyls), which are toxic chemicals that can cause cancer, damage to the immune system, and reproductive problems.
- Dioxins, which are highly toxic chemicals that can cause cancer, birth defects, and damage to the immune system.
- Pesticides and herbicides, such as agent orange, which can cause a range of health effects, including cancer, birth defects, and neurological damage.

The release of chemical waste during war can have severe and long-lasting effects on public health, the environment, and the sustainability of affected regions.

10.7. Thermal pollution

There are many different factors that contribute to pollution, including carbon emissions, personal pollution, waste, and a variety of other factors. Thermal pollution is often overlooked.

Our modern society, however, faces a real and persistent threat from thermal pollution. Basically, thermal pollution occurs when an industry or other human-made organization takes water from a natural source and cools it down or heats it up. Then they pour that water back into the natural resource, which changes the oxygen levels and can adversely affect local communities and ecosystems.

Human activity can cause thermal pollution, which is the sudden change in temperature of a natural body of water, whether it is an ocean, lake, river, or pond. Usually, this happens when a plant or facility takes in water from a natural resource and returns it to a different temperature. They usually use it as a cooling method for their machinery or to help better produce their products.

Fig.10.4: Gases release from stocks

Often, plants that produce different products or wastewater facilities are responsible for this massive exodus of thermal pollution. The effects of thermal pollution remain lingering even after humans and governments have taken many steps to manage how plants are able to use the water in order to properly control and maintain thermal pollution.

Causes of Thermal Pollution

Environmental organizations have already begun fighting thermal pollution, although it is less commonly discussed than other forms of pollution.

As a result of industrial activity, heat is introduced into the environment in an uncontrolled manner, for example:

1. Water as a Cooling Agent in Power, Manufacturing and Industrial Plants

The main source of thermal pollution is production and manufacturing plants. Water is drawn from nearby sources to cool machines and then released back to the source at higher temperatures. When heated water returns to the river or ocean, the temperature rises sharply.

For overheated machinery, different power plants use water as a cooling agent. Since the water used to cool the machines is so hot, power plants send it back to the bodies of water where it was sourced, because it is so hot.

In addition to power plants, chemical plants, steel mills, pulp and paper mills, and other industrial facilities also contribute to thermal pollution. Water is also used to cool different machinery at these facilities, and wastewater containing elevated temperatures is disposed of in various water bodies.

As well as using a lot of water for machine cooling and dumping radioactive waste into different bodies of water, desalination and nuclear plants also use a lot of water as machine cooling. The waste from these plants, which accumulates temperature easily, also causes changes in temperature in the bodies of water, resulting in thermal pollution.

Fig.10.5: Cooling tower and water discharge of a nuclear power plant

Changes in oxygen levels in the water can also affect wildlife living under water, as well as streamside vegetation, which depends on constant oxygen levels and temperatures for survival. If industries are not controlled and careful about their practices, they are essentially damaging these marine-based life forms' quality of life.

2. Soil Erosion

Thermal pollution is also caused by soil erosion, which causes water bodies to rise, exposing them to more sunlight, thus raising their temperatures.

In addition to the general erosion of soil, the stream banks may also erode, exposing the water to even more thermal radiation from the sun, resulting in an even higher temperature in bodies of water.

It may result in anaerobic conditions and an increase in microbial activity in aquatic biomes, while the increase in water temperature may kill some animals since warm bodies of water cannot support them.

3. Deforestation

Normally, trees and plants prevent sunlight from falling directly on lakes, ponds, and rivers. When deforestation occurs, these water bodies are directly exposed to sunlight, absorbing more heat.

Additionally, forests and vegetation cover reflect back and absorb the sun's heat in addition to providing shade for different bodies of water. By doing so, less heat will be around, preventing thermal pollution in the various bodies of water near the forests.

As a result of deforestation, greenhouse gases, i.e., global warming, are released into the atmosphere; the higher the atmospheric temperature, the higher the water temperature.

4. Runoff from Paved Surfaces

Surface waters can be warmed by urban runoff discharged from paved surfaces like roads and parking lots. During summer seasons, pavement gets quite hot, leading to warm runoff that gets into sewers and water bodies.

5. Natural Causes

Several natural causes can cause water bodies to rise in temperature, such as volcanoes, geothermal vents, and hot springs under the oceans and seas. It is also possible for lightning to release massive amounts of heat into the ocean. As a result, the water source's temperature will rise, which will have an adverse effect on the environment.

6. Retention Ponds

Thermal shock can also occur in retention ponds, which absorb a considerable amount of heat energy from the sun because they are relatively shallow and small.

It is similar to pouring a hot pitcher of water into a bathtub full of water and causing the temperature to jump a few degrees Fahrenheit when it is pumped directly into a river, lake, or bay.

7. Domestic Sewage

Municipal water sewage is normally warmer than receiving water. It is often discharged into rivers, lakes, canals, and streams without treatment.

In anaerobic conditions, dissolved oxygen (DO) decreases as the temperature of the receiving water rises, causing the demand for oxygen to increase.

8. Thermoelectric Power Generation

It is common to build thermoelectric power plants next to bodies of water to ensure they have a steady supply of water for their production. Water is converted into steam and drives turbines to generate electricity.

With that being said, the remaining wastewater is being sent back to the body of water it was gathered from, which causes thermal pollution since it absorbs a lot of heat.

The sudden change in temperature in the bodies of water where the wastewater is being disposed of is disrupting and affecting aquatic organisms, causing further aquatic problems.

9. Hydroelectric Power Generation

By altering the natural flow of a river or body of water, hydropower can be harnessed. Through the use of turbines and generators, kinetic energy from the flowing water is converted into electricity.

Despite being a renewable energy source, hydroelectricity has some disadvantages, including causing thermal pollution. Streams are heated by steam-heated turbines as they rotate continuously within them. Thermal pollution is caused as a result.

10.9. Effects of Thermal Pollution

When it comes to the effects of thermal pollution, there are generally two schools of thought among recognized scientists and scholars. The negative effects of this pollution are argued by some to be detrimental to positive environmental practices and to marine ecosystems.

It is, however, argued that some of the most basic aspects of human life would be rendered obsolete without these industries.

The effects of thermal pollution on ecosystems, however, far outweigh the benefits that industries gain by participating in the practice. Wastewater would not be able to be properly maintained. We would not have industries that could produce what we needed.

1. Decrease in Dissolved Oxygen (DO) Levels

As the water's temperature rises, the levels of dissolved oxygen in the water decrease. Warm water is incapable of holding oxygen, so it holds less oxygen. In addition to creating anaerobic conditions, a decrease in DO can suffocate plants and animals, such as fish, amphibians, and copepods.

Growing algae in warm waters can deplete oxygen levels in the water over time, as warm water allows algae to flourish.

2. Increase in Toxins

There is a huge increase in toxins that are being regurgitated into the natural bodies of water because of the constant flow of high-temperature discharge from industries. It is possible that these toxins contain chemicals or radiation, which may adversely affect the local ecology and make them susceptible to different illnesses.

3. Loss of Biodiversity

The loss of biodiversity may be significant if biological activity in the water is reduced. A change in the environment may cause some species of organisms to relocate to another location, while a number of species may migrate in because of warmer waters.

It may be advantageous for organisms that can adjust easily to warmer temperatures over organisms that are not used to them.

Fig.10.6: Industrial pollutions

4. Ecological Impact

Insects, fish, plants, and amphibians can be killed in mass by sudden thermal shock. Some species may benefit from hotter water, while others may die from it. Activities increase with smaller water temperatures, while activities decrease with higher temperatures.

It is well known that many aquatic species are sensitive to small temperature changes, such as a change in temperature of one degree Celsius, which can have a negative impact on their metabolism and other aspects of cellular biology.

5. Affects Reproductive Systems

Increasing temperatures can cause a significant halt in marine wildlife reproduction (although it is true that fish can reproduce – but there is a greater likelihood of birth defects) as reproduction is possible within a certain range of temperatures. If temperatures are too high, immature eggs may be released or certain eggs may not be able to develop normally.

6. Increases Metabolic Rate

When organisms are exposed to thermal pollution, their metabolic rate increases due to increased enzyme activity, which results in them eating more food than they would normally consume if their environment had not changed. As a result, the food chain is disrupted and species composition is altered.

7. Migration

As a result of the warm water, certain species of organisms may migrate into an environment that would suit their survival requirements, disrupting the food chain for other species that depend on them.

10.10. Solutions to Thermal Pollution

The detrimental effects of thermal pollution on the aquatic ecosystem in the future require solutions. A number of methods have been proposed and developed to convert thermal effluents from power plants into useful heat resources for maximizing the benefits. Thermal discharge into water bodies can be handled in the following ways:

1. Cooling Ponds

It is easiest to regulate thermal discharges using cooling ponds or reservoirs. In cooling ponds, heated effluents dissipate heat into the atmosphere and minimize the volume and area of water.

Despite being the simplest and cheapest method of cooling the water, this method is less desirable as well as inefficient in terms of air-water contact.

2. Cooling Towers

The cooling process involves returning water to the water body after it passes through the condenser after being used for cooling purposes.

As such, cooling towers are designed to control the temperature of water so that the cooling process is more efficient. Cooling towers are primarily used to dissipate recovered waste heat, thus preventing thermal pollution.

Fig.10.7: The two wide, concave structures are cooling towers.

3. Artificial Lake

An alternative to a natural lake is an artificial lake, a water body created by humans. The heated effluents can be discharged into the lake at one end, and the water can be withdrawn from the other end for cooling purposes. It is necessary to replenish these lakes continuously, however, because the heat dissipates through evaporation.

4. Water Recycling

Thermal pollution can be mitigated by recycling industrially treated water for domestic use or industrial heating.

5. Other Applications

It is possible to use the thermal discharge (rejected heat) of power plants for other purposes, such as:

- The heating of industrial and commercial spaces.
- Warming of soil is an example of a biological application.
- Among the uses of greenhouse heating are fish culture, livestock shelters, and livestock shelters.

Colder regions or locations are most likely to benefit from these potential physical applications.

There is no doubt that the effects of thermal pollution outweigh the human need to do it. Even though plants and industries have found ways to reduce thermal pollution, most of them do not practice them due to the fact that the traditional model is much easier to work from. It is imperative that we change our attitude toward thermal pollution if we are to promote the thriving environment surrounding marine biology.Knowing the causes and effects can help you make a significant impact on how these plants operate, and you can choose to make the necessary changes.

10.11. Summary

Radioactive waste is the release of high-energy particles or radiation into the environment, which can occur naturally or from human-made sources such as nuclear power plants, nuclear weapons testing, and medical procedures that use radioactive materials. The health effects of radioactive waste depend on the type and amount of radiation exposure and can include radiation sickness, cancer, and other chronic diseases. Radioactive waste can have severe and long-lasting effects on public health, the environment, and the sustainability of affected regions. Thermal pollution is the release of heated water or air into the environment, typically from industrial processes or power plants. This can cause changes in the temperature of bodies of water, which can negatively impact aquatic ecosystems and the organisms that rely on them. The effects of thermal pollution can include reduced oxygen levels in the water, changes in the timing of biological events, and the displacement or extinction of certain species. Thermal pollution can also affect human health, particularly in areas where water is used for drinking or recreation. Overall, both radioactive waste and thermal pollution can have severe and long-lasting effects on public health, the environment, and the sustainability of affected regions. It is important to take steps to reduce and prevent these types of pollution to protect our planet and the health of all living beings.

10.12. Terminal questions

Q.1. What is the nuclear waste? Discuss the nuclear power plants-based waste material discharge.

Answer: --

Q.2. What is the wet solid and liquid waste? Discuss the difference between solid and liquid waste.

Answer: --

Q.3. What is the radioactive waste? Discuss radioactive waste release during war.

Answer: --

Q.4. Discuss the waste discharge form war.

Answer: --

Q.5. What is thermal pollution? Discuss it cause and effects.

Answer: --

Q.6. Discuss the effects of radioactive waste on human beings.

Answer: --

10.13. Further suggested readings

1. Waste treatment and disposal, Williams, Paul T. John Wiley Publishers, 2013.
2. E-waste: Implications, regulations and management in India and Current global best practices, TERI press, Johri, Rakesh.
3. Bio- medical waste management, Sahai, Sushma, APH Publishing.
4. Electronic waste management, design, analysis and application, R E Hester, Cambridge Royal Society of Chemistry.
5. Solid and Hazardous Waste Management, Rao, M.N. and Sultana, BS Publications, Hyderabad.

Unit-11: Instrumental Techniques

Contents

11.1. Introduction

There are several instrumental techniques used for environmental sample analysis. The choice of technique depends on the nature of the sample, the target analytes, and the specific analysis requirements. Different techniques offer unique capabilities in terms of sensitivity, selectivity, and detection limits, allowing for comprehensive characterization of environmental samples. There are several detection techniques such as Gas Chromatography (GC), High-Performance Liquid Chromatography (HPLC), Ion Chromatography (IC), Fourier Transform Infrared Spectroscopy (FTIR), Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Atomic Absorption Spectroscopy (AAS), X-ray Fluorescence Spectroscopy (XRF), Mass Spectrometry (MS), Ultraviolet-Visible Spectroscopy (UV-Vis), Capillary Electrophoresis (CE), Thermal Desorption-Gas Chromatography-Mass Spectrometry (TD-GC-MS), Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GC-MS), Solid-Phase Microextraction (SPME), Total Organic Carbon Analysis (TOC), Isotope Ratio Mass Spectrometry (IRMS), Liquid Chromatography-Mass Spectrometry (LC-MS), X-ray Diffraction (XRD), Scanning Electron

Microscopy (SEM) and Transmission Electron Microscopy (TEM) techniques are directly and indirectly used for the environmental analysis sample of water, air and solid and also used for biological and physical analysis samples.

Objectives

- To discuss the various instrumental techniques used for environmental sampling analysis.
- To discuss FTIR and Mass spectroscopy for water, air and soil analysis.
- To discuss the ion selective electrode for air, water and soil analysis.
- To discuss the total organic carbon analysis.

11.2. Atomic absorption spectroscopy (AAS)

The Absorption spectroscopy, as per name is based on the absorption of electromagnetic radiations by matter. Electron presents in an atom, absorb energy from electromagnetic radiations which fall on it and jump from ground state to excited state. This phenomenon is called absorption and spectroscopy related to it is termed as absorption spectroscopy. An absorption spectrum is measured as a function of wavelength emitted for environmental samples. The absorption spectrum of an atom or molecule depends on its energy level structure and useful for identification of compounds. As it is clear from the name, atomic absorption spectroscopy (AAS) that this spectroscopy deals with the absorption of electromagnetic radiation of specific wavelength by atom.

The first AA Spectrometer was built by scientist *Alan Walsh* at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in 1954, Division of Chemical Physics, in Melbourne, Australia.

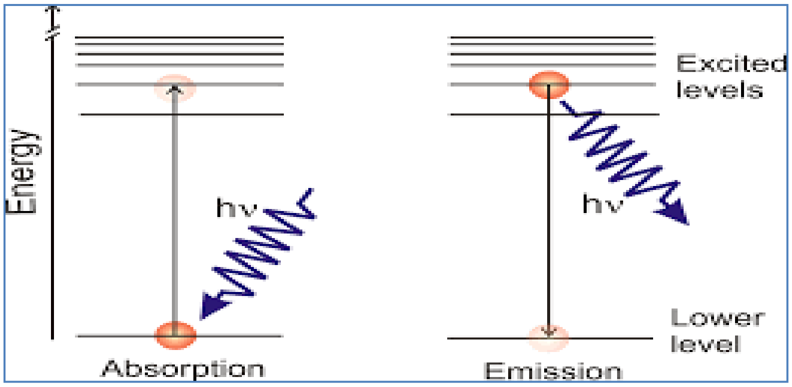

Fig.1.2: Absorption and Emission of electromagnetic radiation

However, the atomic absorption spectroscopy is a spectro-analytical technique that is based on the absorption wavelength which is associated with transition that requires a minimum of energy change. The electronic transition in atom are limited by the availability of empty orbital, because one orbital can be occupied with maximum of two electrons and spin of electron need to be paired in anti parallel fashion. The analytes molar concentration is determined from the amount of absorption. The sample used in atomic absorption spectroscopy, needs to volatile by using the higher energy. Thus, the tested sample either liquid should be converted into vapor form. Atomic absorption is very unique technique for detecting specific metals and its concentration present in the sample as part per million (ppm) or mg/g.

Concentration analysis by atomic absorption spectroscopy is carried out by comparison with calibration standard. It finds extensive applications in the analysis for trace metals in biological serum and drinking water. Some examples of elements detected by AAS are as given below.

Table.1.3: Some elements detected by AAS.

S. No.	**Element**	**Wavelength (nm)**	**Limit of Detection (meu g/mL)**
1	Au	243	0.009
2	Hg	254	0.160
3	Cu	325	0.002
4	Ag	328	0.002

5	U	358	3900
6	Ca	423	0.002
7	Na	589	0.0002
8	K	767	0.002

Principle:

AAS is based on the principle of atomic absorption, where atoms in a gaseous state absorb light at specific wavelengths corresponding to their characteristic electronic transitions. The concentration of an analytes element in a sample is determined by measuring the absorption of light at a specific wavelength after passing through the sample.In AAS the free atoms (gas) generated in an atomizer can absorb radiation at specific frequency. Atomized element absorbs energy of a wavelength that is peculiar to that element. In the process of atomization the hallow cathode lamp is used as a light source which emits light of wavelength that is peculiar to that element. When a beam of electromagnetic radiation of a particular wavelength is passed through the vaporized atom present in the flame, the atoms absorb the radiation and extent of radiation will be directly proportional to the number of ground state atoms presented in the flame. Atomic-absorption spectroscopy quantifies the absorption of ground state atoms in the gaseous state. The atoms absorb ultraviolet or visible light and make transitions to higher electronic energy levels. The analyte concentration is determined from the amount of absorption of electromagnetic radiation. The atomic absorption is a very common technique for detecting metals and metalloids in environmental samples.

Instrumentation

The Atomic absorption spectroscopy has simple instrumentation. Every absorption spectrometer must have the three basic component requirements (1) a light source; (2) a sample cell; and (3) a means of specific light measurement. But, unlike other spectroscopy methods, it has two additional requirements. These include a specially designed lamp to produce light of a desired wavelength and a burner to prepare the sample for absorption of light radiation. Additionally, the instrument also sprays the sample in the solution state over an atomizer (burner). This leads to evaporation of the solvent and leaves a fine dry residue. This residue has neutral atoms in the ground state. The sample of interest is aspirated and atomized into the flame. If that metal is present in the sample, its atoms will absorb some of the light, thus reducing its intensity. This decrease in intensity of the light is the process of atomic absorption. The instrument measures the change in intensity. A computer data system converts this change into an absorbance.

i. Only liquid samples can be analyzed
ii. Non metalcont be analyzed
iii. It may be used for quantitative analysis under special circumstances

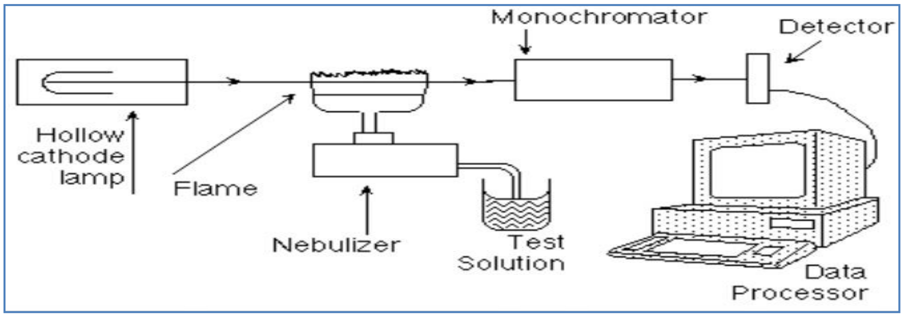

Fig.1.3: Diamagnetic representation of AA spectrophotometer

An atom absorbs light at discrete wavelengths. So, it is necessary to use a light source, which emits the specific wavelengths which can be absorbed by the atom. The two most common light sources used in AA are the ‘‘hollow cathode lamp’’ and the ‘‘electrode less discharge lamp. The light should be stable and have sufficient intensity and should produce a narrow spectrum with little background noise.Hollow cathode lamps (HCL) are the most common radiation source in AAS. It contains a tungsten anode and a hollow cylindrical cathode made up of metal to be determined. For instance, if sodium is to be analyzed from the sample, a cathode coated with sodium is used. These are sealed in a glass tube filled with an inert gas like argon or neon which is ionized by an electric arc. The ions get attracted toward cathodes and strike it leading to excitation of metal ions. This leads to the emission of radiation with a characteristic wavelength of analyte metal.The advantage of hollow cathode lamp is that it provides radiation with a bandwidth of 0.001 to 0.01nm. So these lamps give highly specific radiation. The disadvantage of this hollow cathode lamp is that for every metal different cathode lamp has to be employed.

Nebulizer sucks up the liquid sample at controlled rate and creates fine aerosol spray that mixes with fuel and oxidant and where it utilized by exposing them to higher thermal energy and introduce into the flame. The nebulizer uses the combustion flames to atomize and introduce the sample into the light path. More small the size of the droplets produced, more high will be the sensitivity of the element tested. Alternating, the gases form can be generated by using induced coupled plasma (ICP).

Atomization is separation of particles into individual molecules and breaking molecules into atoms. This is done by exposing the analyte to high temperatures in a flame or graphite furnace. The (spectroscopic) flames and electrothermal (graphite tube) atomizers are the two most common atomizers used nowadays. Other atomizers, such as glow-discharge atomization, hydride atomization, or cold-vapor atomization might be used for special purposes.

Flame atomizers is the oldest and most commonly used atomizers. In this atomizer air-acetylene flame with a temperature of about 2300 ℃ or air-nitrous oxide flame with a temperature of about 2700 ℃ are used. Liquid or dissolved samples are typically used with flame atomizers. In flame AAS; a steady-state signal is generated during the time period when the sample is aspirated. This technique is typically used for determinations in the mg L^{-1} range, and may be extended down to a few μg L^{-1} for some elements.

Electrothermal atomizer uses graphite coated furnace to vaporize the sample. The graphite tubes are heated using a high current power supply. In ET AAS a transient signal is generated, the area of which is directly proportional to the mass of analyte (not its concentration) introduced into the graphite tube. This technique has the advantage that any kind of sample, solid, liquid or gaseous, can be analyzed directly.

Monochromator is a very important part of an AA spectrometer used to select the specific wavelength of light from the lines emitted by the Hollow cathode lamp and transmit it to the detector. It not only selects the specific analytical line, but excludes all other interfering lines in that region. The selection of specific light allows the determination of the selected elements in the presence of others.

Detector detects the intensity of radiation absorbed by the elements. The detector consists of a photomultiplier tube or simple photocell. The PMT determines the intensity of photons of the analytical line exiting the monochromator.

The processing of electrical signal is fulfilled by a signal amplifier. The signal from the PMT is converted to digital format by a transducer for read-out, or further fed into data station for printout by the requested format. The unknown concentration of the element is then calculated from the calibration curve. The absorbance of each known solution is measured and after that calibration curve of absorbance is plotted against concentration.

Sample preparation

Sample preparation plays a crucial role in atomic absorption spectrometry (AAS) analysis of environmental samples. Proper sample preparation ensures accurate and reliable results by minimizing interferences and enhancing the sensitivity of the measurement. Here are the general steps involved in sample preparation for AAS analysis of environmental samples, along with examples:

- **Sample Collection:** Collect representative samples of the environmental matrix you want to analyze, such as water, soil, sediment, or biota (e.g., plants, animals). Follow appropriate sampling guidelines and procedures to ensure sample integrity.
- **Sample Pre-treatment:** Depending on the sample matrix and the target analytes, pre-treatment steps may be required. Common pre-treatment techniques include filtration, digestion, extraction, and purification.
- **Filtration:** If the sample contains suspended particles or debris, filtration may be necessary to remove these interferences. Filtration methods involve passing the sample through a filter membrane to retain solids while allowing the liquid portion to pass through. Example: Filtration of water samples to remove particulate matter before analysis.
- **Digestion:** For solid samples like soil, sediment, or biota, digestion is often necessary to dissolve the analytes and convert them into a form suitable for AAS analysis. Digestion methods involve the use of acids or mixtures of acids to break down the sample matrix and release the target elements. Example: Acid digestion of soil samples using a mixture of nitric acid (HNO_3) and hydrochloric acid (HCl) to solubilize metals for analysis.
- **Extraction:** In some cases, extraction techniques may be employed to isolate the target analytes from the sample matrix. Liquid-liquid extraction or solid-phase extraction methods can be used to concentrate the analytes or remove interfering substances. Example:

Extraction of organic contaminants from water samples using appropriate solvents or solid-phase extraction cartridges.

- **Purification:** Environmental samples may contain complex matrices with high levels of interferences. Purification techniques such as precipitation, co-precipitation, or ion exchange can be used to remove interfering substances and improve the accuracy of AAS analysis. Example: Precipitation of interfering ions using specific reagents to remove them from a water sample before AAS analysis.
- **Calibration Standards:** Prepare a series of calibration standards by diluting standard stock solutions of known analyte concentrations. These standards are used to create a calibration curve for quantification. Example: Dilution of certified reference materials of known metal concentrations to prepare calibration standards for water or soil analysis.
- **Quality Control:** Include blank samples (solvent without analytes) and spiked samples (known addition of analytes to blanks) as quality control measures to assess and monitor the accuracy and precision of the analysis. Example: Preparation of blank water samples and spiked soil samples to assess background levels and recovery rates of target elements.

Following established standard operating procedures (SOPs) and quality assurance/quality control protocols is essential for consistent and reliable sample preparation in AAS analysis. Specific sample preparation procedures may vary depending on the sample matrix, target analytes, and specific analytical requirements.

Application

AAS has both qualitative and quantitative application in different areas. The modern emission spectrophotometers allow determination of about 20 elements in biological samples, the most common being calcium, magnesium and manganese. Absorption spectrophotometers are usually more sensitive than emission instruments and can detect less than 1 ppm of each of the common elements with the exception of alkali metals. The relative precision is about 1% in a working range of 20–200 times the detection limit of an element. It’s used in environmental samples, such as water, soil, sediment, or biological tissues, require appropriate sample preparation techniques before analysis by AAS. The sample preparation methods can include digestion, extraction, filtration, dilution, or separation techniques, depending on the sample matrix and the desired analytes form. The AAS is applied in a wide range of environmental analysis applications, including:

- **Water Analysis:** AAS is commonly used for the analysis of metals in water samples. It can determine the concentrations of elements such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), and copper (Cu) in drinking water, surface water, wastewater, and groundwater. Monitoring these metals is crucial for assessing water quality and ensuring compliance with regulatory standards.
- **Soil Analysis:** AAS is employed for the analysis of metals in soil samples. It can determine the levels of essential elements like iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) in agricultural soils. AAS is also useful for measuring potentially toxic elements such as lead (Pb), cadmium (Cd), and arsenic (As) in contaminated soils, providing insights into soil pollution and remediation efforts.
- **Air Quality Monitoring:** AAS is utilized in the analysis of air samples to measure the concentrations of trace metals and metalloids. It can determine elements like lead (Pb), arsenic (As), cadmium (Cd), and nickel (Ni) in particulate matter collected from air filters. These measurements help in assessing air pollution levels and understanding the sources and impacts of airborne contaminants.
- **Food and Beverage Analysis**: AAS is employed for the analysis of metals in food and beverages. It can determine the concentrations of elements like calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), and copper (Cu) in various food products. AAS is also used for monitoring toxic elements, such as lead (Pb) and cadmium (Cd), in food and beverages to ensure consumer safety and compliance with regulations.
- **Biological and Environmental Samples:** AAS is used for analyzing metals in biological samples, such as blood, urine, and tissues, to assess metal exposure and potential toxicity. It is also applied in the analysis of environmental samples like sediments, plant materials, and biota (e.g., fish, mussels) to investigate metal accumulation and ecological impacts.

These examples highlight the versatility of atomic absorption spectrometry in environmental sample analysis. The technique provides accurate and reliable measurements of trace metal concentrations, enabling researchers and environmental professionals to monitor and evaluate environmental quality and human health risks.

11.3. Inductive couple emissions spectroscopy

Inductively Coupled Plasma Emission Spectroscopy (ICP-OES), also known as ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectroscopy). CP-OES is an analytical technique widely used for the elemental analysis of various samples, including environmental samples.

Principle:

ICP-OES is based on the principle of atomic emission spectroscopy. It utilizes an inductively coupled plasma (ICP) as the excitation source, which generates a high-temperature plasma composed of argon gas. The sample is introduced into the plasma, where it is atomized, vaporized, and ionized. The excited atoms and ions in the plasma emit characteristic light at specific wavelengths, which are detected and quantified to determine the elemental composition of the sample.

Instrumentation:

An ICP-OES instrument consists of several key components, including an argon gas supply, a nebulizer, a spray chamber, a plasma torch, a monochromator, a detector, and a data analysis system. The nebulizer converts the sample into a fine aerosol, which is introduced into the plasma torch. The plasma torch generates the high-temperature plasma, and the resulting emission is passed through a monochromator to select the desired wavelengths. The emitted light is detected by a photomultiplier tube or a charge-coupled device (CCD) detector for quantification.

Sample Preparation:

Environmental samples, such as water, soil, sediment, or biological tissues, usually require appropriate sample preparation techniques before analysis by ICP-OES. The sample preparation is a crucial step in environmental sample analysis using inductively coupled plasma emissions spectroscopy (ICP-OES). Proper sample preparation ensures accurate and reliable results by reducing interferences and improving the analytical performance of the instrument. Here are the general steps involved in sample preparation for ICP-OES analysis of environmental samples:

- **Sample Collection:** Collect representative samples of the environmental matrix you want to analyze, such as water, soil, sediment, or plant material. Follow appropriate sampling guidelines and procedures to ensure the integrity of the samples.
- **Sample Pre-treatment:** Depending on the nature of the sample, pre-treatment steps may be required to remove interferences or concentrate the analytes. Some common pre-treatment techniques include filtration, digestion, extraction, and leaching.
- **Sample Digestion:** For solid samples like soil, sediment, or plant material, digestion is often necessary to convert the analytes into a form suitable for analysis. Digestion methods involve the use of acids or mixtures of acids to dissolve the sample matrix and release the analytes. Microwave digestion or hot plate digestion techniques are commonly employed.
- **Sample Filtration:** After digestion, the sample is typically filtered to remove insoluble particles or undigested material that may clog the ICP-OES instrument or cause blockages in the sample introduction system. Filtration methods include the use of syringe filters or filter papers with appropriate pore sizes.
- **Sample Dilution:** Depending on the concentration range of the analytes and the sensitivity of the instrument, dilution of the sample may be necessary. Dilution with a suitable solvent (e.g., deionized water or acid matrix) ensures that the analyte concentrations fall within the linear range of the instrument and minimizes matrix effects.
- **Calibration Standards:** Prepare a series of calibration standards by accurately diluting standard stock solutions of known analyte concentrations. These calibration standards will be used to generate a calibration curve for quantification.
- **Quality Control:** Include quality control measures such as blank samples (solvent without analytes) and spiked samples (known addition of analytes to blank samples) to assess and monitor the accuracy and precision of the analysis.
- **Instrumental Analysis**: Once the samples are prepared, they are introduced into the ICP-OES instrument for analysis. The sample introduction system, which may include nebulization, vaporization, and atomization processes, converts the sample into an aerosol or vapor that is then introduced into the plasma. The plasma excites the analyte atoms, and the emitted radiation is measured by the spectrometer to determine the elemental concentrations.

Applications:

ICP-OES is widely used in environmental sample analysis for various applications, including:

- Analysis of trace elements and heavy metals in water, soil, sediment, and air samples.
- Monitoring environmental pollutants and assessing their impact on ecosystems.
- Determination of nutrient levels in soil and water for agricultural and environmental studies.
- Analysis of metals and metalloids in biological tissues for biomonitoring and toxicological studies.
- Characterization of geological samples, such as rocks and minerals, for geological and geochemical studies.
- ICP-OES provides accurate and sensitive quantification of a wide range of elements, making it a valuable tool for environmental sample analysis. It enables researchers and analysts to assess environmental quality, monitor pollution levels, study elemental cycles, and understand the interactions between contaminants and the environment.

X-ray fluorescence (XRF) is an analytical technique used for the elemental analysis of various materials, including environmental samples. It provides non-destructive and multi-elemental analysis capabilities, making it valuable for environmental sample analysis. Here's an overview of XRF and its applications in environmental sample analysis:

11.4. X-ray fluorescence (XRF)

X-ray fluorescence (XRF) is an analytical technique used for the elemental analysis of various materials, including environmental samples. It provides non-destructive and multi-elemental analysis capabilities, making it valuable for environmental sample analysis. Here's an overview of XRF and its applications in environmental sample analysis:

Principle:

XRF is based on the principle that when a sample is irradiated with high-energy X-rays, the atoms in the sample are excited and emit characteristic X-ray fluorescence radiation. The emitted X-rays are detected and their energy is analyzed to determine the elemental composition of the sample.

Instrumentation:

XRF instruments consist of several key components, including an X-ray source (typically an X-ray tube), a sample holder, a detector system, and data analysis software. The X-ray source emits high-energy X-rays that interact with the sample. The detector system measures the energy and intensity of the emitted characteristic X-rays, and the data analysis software processes the signals to identify and quantify the elements present in the sample.

Sample Preparation:

Environmental samples may require various preparation techniques before analysis by XRF. These can include grinding, homogenization, pelletization, or fusion to obtain a representative and homogenous sample form that can be analyzed with XRF.

Measurement Procedure:

- **Calibration:** Calibration standards with known elemental compositions are used to calibrate the instrument. These standards cover the range of elements and concentrations expected in the samples.
- **Sample Analysis:** The prepared sample is placed in the sample holder, and X-rays are directed towards it. The X-rays interact with the atoms in the sample, causing the emission of characteristic fluorescent X-rays. The detector system measures the energy and intensity of the emitted X-rays, which are then used to identify and quantify the elements present in the sample.
- **Quality Control:** Quality control measures, such as the use of certified reference materials, blanks, and duplicates, are employed to ensure the accuracy and precision of the analysis. Instrument calibration, stability checks, and regular maintenance are also essential for reliable results.

Applications:

XRF is applied in a wide range of environmental analysis applications, including:

- Analysis of soil and sediment samples for determining elemental concentrations, identifying contaminants, and assessing soil quality.

- Monitoring trace metal levels in water bodies, including lakes, rivers, and oceans, to evaluate water quality and potential contamination.
- Characterization of air particulate matter to study air pollution and identify sources of pollutants.
- Analysis of geological samples, such as rocks and minerals, for mineral exploration and understanding geological processes.
- Assessment of elemental composition in plants, animals, and biological tissues for ecological studies and monitoring of bioaccumulation.
- XRF offers rapid, non-destructive, and multi-elemental analysis capabilities, making it a valuable tool in environmental sample analysis. It provides insights into elemental composition, identifies contaminants, and aids in environmental monitoring and assessment.

11.5. X-ray Diffraction

The powder sample of verity of organic compounds like natural product, steroids, vitamins, antibiotics etc. are best analyzed by XRD. A quantitative identification of crystal is also possible since X-ray diffraction pattern is unique for each crystal like fingerprint. X ray spectroscopy is non destructive techniques to analysis of crystalline material. X-ray absorption, X-ray diffraction and X-ray florescence are the three main field of X-ray spectroscopy. Amongst four techniques, the X ray diffraction (XRD) is most useful in elucidation of structure of compounds. The X-ray diffraction based on its scattering by crystal is extremely important as compared to other. By X- ray diffraction, one can be identify the crystal structure of determine the particle size. The XRD is scarcely used for quantitative analysis but in some time it is also useful in quantitative analysis. The X ray has significance aspect due to much shorter wavelength of about < 0.01 – 10 nm.

The atomic planes of a crystal cause an incident beam of X-rays to interfere with one another as they come out from the crystal. This phenomenon is called X-ray diffraction and it is represented by symbolϖ. X-ray powder diffraction (XRD) is an important tool for identification of phase of crystalline material and its unit cell dimensions. When the monochromatic ray generated by cathode ray tube is collimated to concentrate and directed toward the sample, it produces constructive interference after satisfy with the conditions of Bragg's

Law (nλ=2d sin θ). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted.The average crystalline size of particles was measured by Scherrer’s equation as expressed in Eq. (6.1):

$$D_{\dot{h}kl} = \frac{k\ x\ \lambda}{\beta_{hkl} x\ Cos\theta_{\dot{h}kl}} \qquad (6.1)$$

where $D_{hkl}$is the particle size (nm), perpendicular to the normal line of plane, k is (0.9) $\beta_{hkl}$is the full width at half maximum of the (hkl) diffraction peak, θ is the Bragg angle of (hkl) peak, and λ is the wavelength of X-ray (λ = 0.1540 nm).

Principle

In XRD, the interaction of electromagnetic radiation with matter causes the electron in the exposed sample to oscillate. The secondary waves that are produced by accelerated electron have same frequency as incident radiation. This super-position of waves gives rise to phenomenon of interference. The interference depends on the displacement of two waves. The amplitude of these waves either reinforces or cancels each other out. Thus the maximum interference is called constructive interference and the cancelling is called destructive interference. The interference gives rise to dark and white ring line or spot. Since the distance between atom or ions is of the order of 10^{-1} m (1 Å) different methods are used to determine structure at atomic level. In this case X ray region of electromagnetic radiation is required. X-rays are produced within a closed tube under vacuum atmosphere. The most prevalent type of diffraction to X-ray crystallography is known as Bragg diffraction, which is defined as the scattering of waves from a crystalline structure. Formulated by William Lawrence Bragg, the equation of Bragg's law (equation 1) relates wavelength to angle of incidence and lattice spacing. Because of the nature of diffraction, waves will experience either constructive or destructive interference with other waves. In the same way, when an X- ray beam is diffracted off a crystal, the different parts of the diffracted beam will have seemingly stronger energy, while other parts will have seemed to lost energy.

$$n\lambda = 2d\sin\theta$$

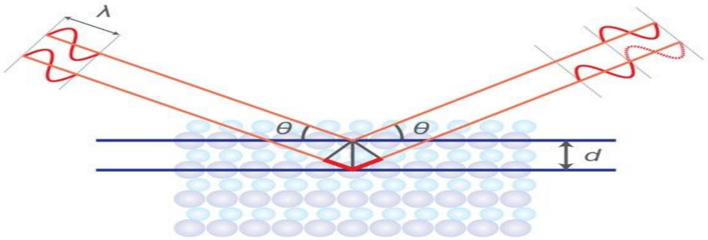

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Fig.6.1: Schematic representation of Bragg’s law interference

where *n* is an integer called the order of reflection, λ is the wavelength of x-rays, *d* is the characteristic spacing between the crystal planes of a given specimen and θ is the angle between the incident beam. By measuring the angles, θ, under which the constructively interfering x-rays leave the crystal, the inter planar spacings *d*, of every single crystallographic phase can be determined.

Instrumentation

X-ray for chemical analysis is carried out by rotating anode generator pr synchrotron facilities. X-rays are the key component in this instrument because it has characteristic character to indentify the object. In rotating anode generators, a rotating metal target is bombarded with high-energy (10–100 keV) electrons that knock out core electrons. An electron in an outer shell fills the hole in the inner shell and emits the energy difference between the two states as an X-ray photon. Common targets are copper, molybdenum and chromium, which have strong distinct X-ray emission at 1.54 Å, 0.71 Å and 2.29 Å, respectively. However, in the x-ray emission copper is used because it has strong target distinct x ray emission at 1.54 Å. That superimposed on a continuous spectrum known as Bremsstrahlung. In synchrotrons, electron is accelerated in ring thus producing a continuous spectrum of x rays that converted into single beam by Monochromator.

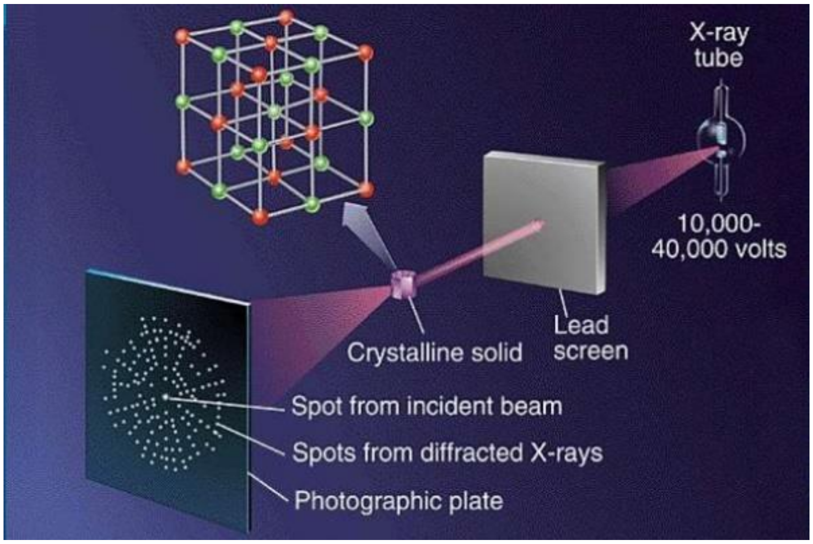


Fig. 11.2: Schematic representation of x-rays production

Sample preparation

Sample preparation for X-ray diffraction (XRD) analysis of environmental samples is crucial to obtain accurate and reliable results. The goal of sample preparation is to prepare a finely ground powder sample that is representative of the material being analyzed. Here are the general steps involved in sample preparation for XRD analysis of environmental samples:

- **Sample Collection:** Collect representative samples of the environmental matrix you want to analyze, such as soil, sediment, rock, or minerals. Follow appropriate sampling guidelines and procedures to ensure sample integrity.
- **Drying:** If the sample contains moisture, it needs to be dried to remove water content. This can be done by air drying or using an oven set at a low temperature. Note that some materials may require special drying conditions to avoid phase changes or loss of volatile components.
- **Grinding and Crushing:** Environmental samples are typically prepared as finely ground powders for XRD analysis. The sample should be crushed to reduce particle size and then ground to a fine powder using a mortar and pestle, ball mill, or other grinding equipment. The goal is to obtain a homogeneous sample with particles small enough to ensure proper X-ray penetration.

- **Sieving:** In some cases, sieving may be necessary to obtain a narrow particle size range or to remove large particles or agglomerates. Select an appropriate sieve size based on the desired particle size distribution and the analysis requirements.
- **Mounting:** If the sample is loose powder or has low cohesion, it may need to be mounted on a sample holder or support. The choice of mounting material depends on the sample characteristics and the analysis technique used. Common options include glass slides, zero-background holders, or specialized sample mounts.
- **Backing Material:** Some samples, especially low-density or friable materials, may require a backing material to provide support and enhance sample stability during analysis. Backing materials can be used to create a flat surface for measurement and to prevent the sample from disintegrating or scattering during X-ray exposure.
- **Sample Alignment:** Proper alignment of the sample is essential to ensure accurate and precise XRD measurements. The sample should be aligned so that the diffracted X-rays strike the detector at the correct angle. Alignment aids such as alignment marks or reference materials can be used to position the sample accurately.
- **Sample Identification and Labeling:** It is crucial to label and identify the prepared samples properly to ensure traceability and prevent confusion during analysis and data interpretation. Record sample details such as sample name, location, date, and any other relevant information.

Application:

Generally in single crystal and powder crystal XRD are used in practice. We know that solid is made-up of particles by regular arrangement. A crystal is a solid in which atoms or molecules are packed in a particular arrangement within the unit cell which is repeated indefinitely along three principal directions in space. Crystals can be formed by a wide variety of materials, such as salts, metals, minerals and semiconductors, as well as various inorganic, organic and biological molecules. The crystal is subjected to X-ray produced by rotating anode generator or synchrotron facilities. The diffraction pattern of regularly spaced spots known as reflection is recommended a detector. Some of biological sample such as DNA and cytoskeleton components does not makes crystalline form, but they form fibber in long structure which are parallel to each other. Generally two class of fiber diffraction such as crystalline fiber (A form DNA) and non crystalline fiber (B from DNA) is distinguished.

A form of DNA, the molecules packed to form these micro crystals randomly arranged the axis. While B form of DNA molecules packed to form this micro crystals are arranged parallel to other but random orientation around the common axis. However, XRD is a nondestructive technique to identify crystalline phases and orientation. Multi components mixture of crystal will be analyzed by XRD with need of extensive sample preparation. In this types of XRD study all types of crystalline orientation are equally represented. The data of powder XRD is compared with known standard or to database (Powder diffraction file) for identification of individual components. Powder diffraction is a rapid method to analyze multicomponent mixtures without the need for extensive sample preparation. Instead of using single crystals, the solid material is analyzed in the form of a powder where, ideally, all possible crystalline orientations are equally represented.

11.6. Fourier Transform Infrared (FT-IR)

Fourier Transform Infrared (FT-IR) spectrometry is widely used techniques. It is a non destructive and less time consuming technique. FTIR method is used to obtain the infrared spectrum of transmission or absorption of a fuel sample. FTIR identifies the presence of organic and inorganic compounds in the sample. Depending on the infrared absorption frequency range 600–4000 cm^{-1}. FTIR is useful in identifying and characterizing unknown materials, detecting contaminants in a material, finding additives, and identifying decomposition and oxidation. It is a powerful tool for identifying types of chemical bonds in a molecule by producing an infrared absorption spectrum that is like a molecular "fingerprint". The wavelength of light absorbed is characteristic of the chemical bond as can be seen in this annotated spectrum.

Fourier Transform Infrared Spectroscopy (FTIR) identifies chemical bonds in a molecule by producing an infrared absorption spectrum. The spectra produce a profile of the sample, a distinctive molecular fingerprint that can be used to screen and scan samples for many different components. FTIR is an effective analytical instrument for detecting functional groups and characterizing covalent bonding information. FTIR provide following information such as

It provide spectral region is in the infrared
It provide spectra of high resolution
It application involves in weak signals
It provides spectra quickly with in high S/N ratio

It provides high spectral accuracy

FTIR simultaneously collect high spectral resolution data over a wide NIR to FIR range spectra. In FTIR studies of molecules, the absorption information is generally obtained in the form of both wave number and absorption intensity or percent transmittance. The spectrum is generally showing wave number (cm^{-1}) as the x-axis and absorption intensity or percent transmittance as the y-axis. The value of transmittance (T) denotes the radiant power transmitted by the sample (I) to the radiant power incident on the sample (I_0). Absorbance (A) is the logarithm to the base 10 of the reciprocal of the transmittance (T).

The absorption intensity of molecules vibration can be determined by the Lambert-Beer Law expressed-

$$A = \varepsilon . c . l$$

where 'A' is the measured absorbance,$'\varepsilon'$is a wavelength dependent adsorptive coefficient, 'l' is the path length,and 'c' is the analyte concentration.

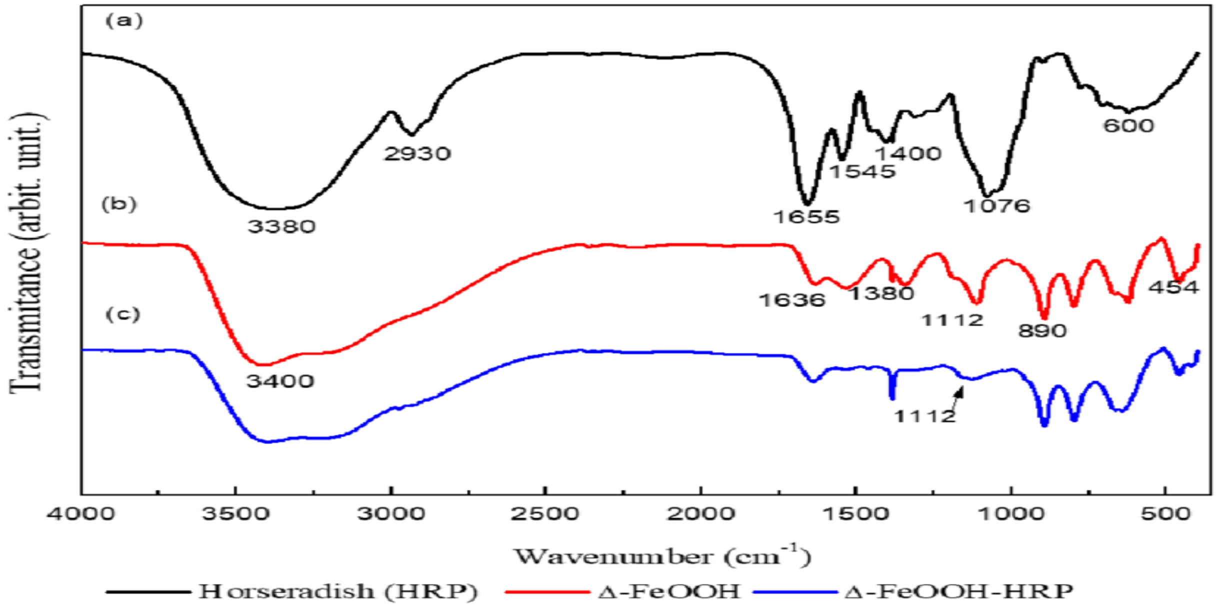


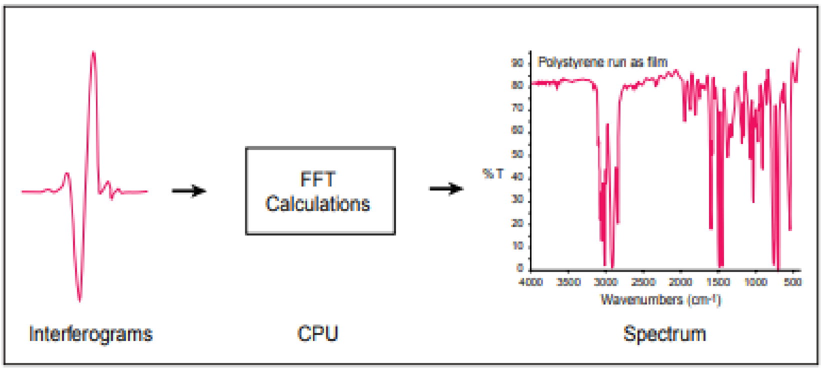
Fig: FTIR spectra of (a) horseradish peroxidase (HRP); (b) Δ-FeOOH particles; and (c) Δ-FeOOH-HRP

Principles

Molecular bonds vibrate at various frequencies depending on the elements and the type of bonds. For any given bond, there are several specific frequencies at which it can vibrate. According to quantum mechanics, these frequencies correspond to the ground state (lowest frequency) and several excited states (higher frequencies). One way to cause the frequency of a molecular vibration to increase is to excite state, the Infrared light from the light source passes through a Michelson interferometer along the optical path.

The Michelson interferometer comprises a beam splitter, moving mirror, and fixed mirror. The light beam split into two by the beam. The two beams reflect off of their respective mirrors and are recombined when they meet back at the beam splitter. Because the path that one beam travels is a fixed length and the other is constantly changing as its mirror moves, the signal which exits the interferometer is the result of these two beams "interfering" with each other. The resulting signal is called an interferogram which has the unique property that every data point (a function of the moving mirror position) which makes up the signal has information about every infrared frequency which comes from the source. This means that as the interferogram is measured; all frequencies are being measured simultaneously. Thus, the use of the interferometer results in extremely fast measurements.

A means of "decoding" the individual frequencies is required. This can be accomplished via a well-known mathematical technique called the Fourier transformation. This transformation is performed by the computer which then presents the user with the desired spectral information for analysis



The Sample Analysis Process in FTIR

The FTIR instrument sends infrared radiation of about 10,000 to 100 cm^{-1} through a sample, with some radiation absorbed and some passed through. The absorbed radiation is converted into rotational and/or vibrational energy by the sample molecules. The resulting signal at the detector presents as a spectrum, typically from 4000 cm^{-1} to 400cm^{-1}, representing a molecular fingerprint of the sample. The normal instrumental process is as follows:

The Source:

Infrared energy is emitted from a glowing black-body source. This beam passes through an aperture which controls the amount of energy presented to the sample (and, ultimately, to the detector).

The Interferometer:

The beam enters the interferometer where the "spectral encoding" takes place. The resulting interferogram signal then exits the interferometer.

The Sample:

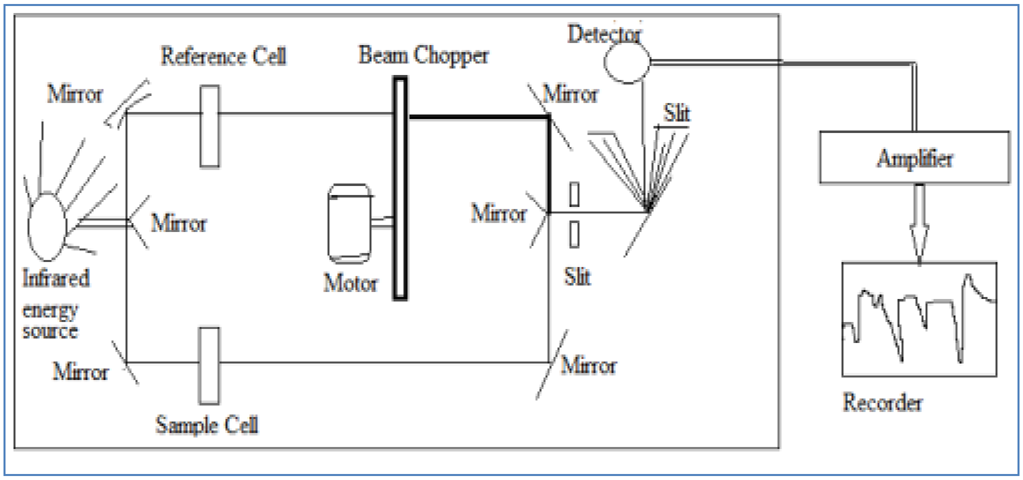
The beam enters the sample compartment where it is transmitted through or reflected off of the surface of the sample, depending on the type of analysis being accomplished. This is where specific frequencies of energy, which are uniquely characteristic of the sample, are absorbed.

The Detector:

The beam finally passes to the detector for final measurement. The detectors used are specially designed to measure the special interferogram signal.

The Computer:

The measured signal is digitized and sent to the computer where the Fourier transformation takes place. The final infrared spectrum is then presented to the user for interpretation and any further manipulation.



Sample preparation

Sample preparation for Fourier-transform infrared (FTIR) analysis of environmental samples is important to obtain accurate and reliable results. The goal of sample preparation is to prepare the sample in a suitable form for analysis, ensuring that it is representative of the material being studied. Here are the general steps involved in sample preparation for FTIR analysis of environmental samples, along with examples:

- **Sample Collection:** Collect representative samples of the environmental matrix you want to analyze, such as water, soil, sediment, air particulates, or organic materials. Follow appropriate sampling guidelines and procedures to ensure sample integrity.
- **Sample Homogenization:** If the sample is heterogeneous, it may need to be homogenized to ensure that the measured FTIR spectrum is representative of the entire sample. Mixing, grinding, or crushing can be performed depending on the sample type. Example: Homogenization of soil samples to ensure a representative analysis of different layers or regions within the sample. The specific sample preparation steps can vary depending on the sample type and the intended analysis. Here are some common examples:
  i. **Solid Samples:** Solid samples may need to be ground into a fine powder to ensure a homogeneous mixture and optimal interaction with infrared radiation. Avoid excessive heating during grinding to prevent any thermal changes in the sample. Example: Grinding rock or mineral samples into a fine powder for FTIR analysis.
  ii. **Liquid Samples:** Liquid samples may require solvent evaporation to obtain a solid residue for FTIR analysis. Solvents that do not interfere with the measurement, such as water, ethanol, or acetone, can be used. Example: Evaporation of a water sample to obtain solid residues for FTIR analysis of dissolved organic compounds.
  iii. Gas Samples: Gas samples can be directly introduced into an FTIR gas cell or adsorbed onto a suitable solid substrate for analysis. Example: Adsorption of air pollutants onto activated carbon filters for FTIR analysis of volatile organic compounds. Sample

Presentation: The prepared sample needs to be presented to the FTIR instrument for analysis. Different approaches can be used, including:

i. Transmission: Solid samples can be compressed into pellets or pressed between salt plates for transmission measurements. Example: Compression of powdered soil sample into a pellet for FTIR analysis.

ii. Attenuated Total Reflectance (ATR): ATR accessories can be used to analyze solid or liquid samples without extensive sample preparation. The sample is pressed against a crystal surface, allowing for direct measurement. Example: Placing a thin film of an oil sample onto an ATR crystal for FTIR analysis.

iii. Gas Cell: For gas samples, a gas cell with appropriate path length can be used to directly measure the gas-phase absorption spectrum. Example: Introduction of a gas sample into a gas cell for FTIR analysis of atmospheric pollutants.

Application of FTIR

Fourier Transform Infrared Spectroscopy (FTIR) is a powerful analytical technique used in environmental sample analysis for the identification and characterization of organic and inorganic compounds based on their absorption of infrared radiation. FTIR spectra reveal the composition of solids, liquids, and gases. Here are some key applications of FTIR in environmental sample analysis are:

1. FTIR is widely used to identify and analyze organic compounds present in environmental samples. It can help in the identification of pollutants, such as volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), pesticides, and other organic contaminants. FTIR spectra of these compounds serve as unique "fingerprint" patterns, enabling their identification and quantification.
2. FTIR can be employed to analyze airborne particulate matter, including fine particulate matter (PM2.5) and inhalable particulate matter (PM10). It allows for the characterization of the chemical composition of particulate matter, including the identification of organic compounds, minerals, and inorganic pollutants. This information aids in assessing air quality, identifying pollution sources, and studying the health effects of particulate matter.
3. FTIR is used to analyze soil and sediment samples, providing valuable information about their composition and properties. It helps identify organic matter content, mineral composition, clay minerals, soil organic carbon, and contaminants present in the samples. FTIR can be used to monitor soil quality, assess contamination levels, and study soil processes and interactions.
4. FTIR is utilized in the analysis of water samples to assess their quality and detect pollutants. It aids in identifying and quantifying organic compounds, such as phenols, aldehydes, and chlorinated hydrocarbons, as well as inorganic compounds like nitrates, phosphates, and

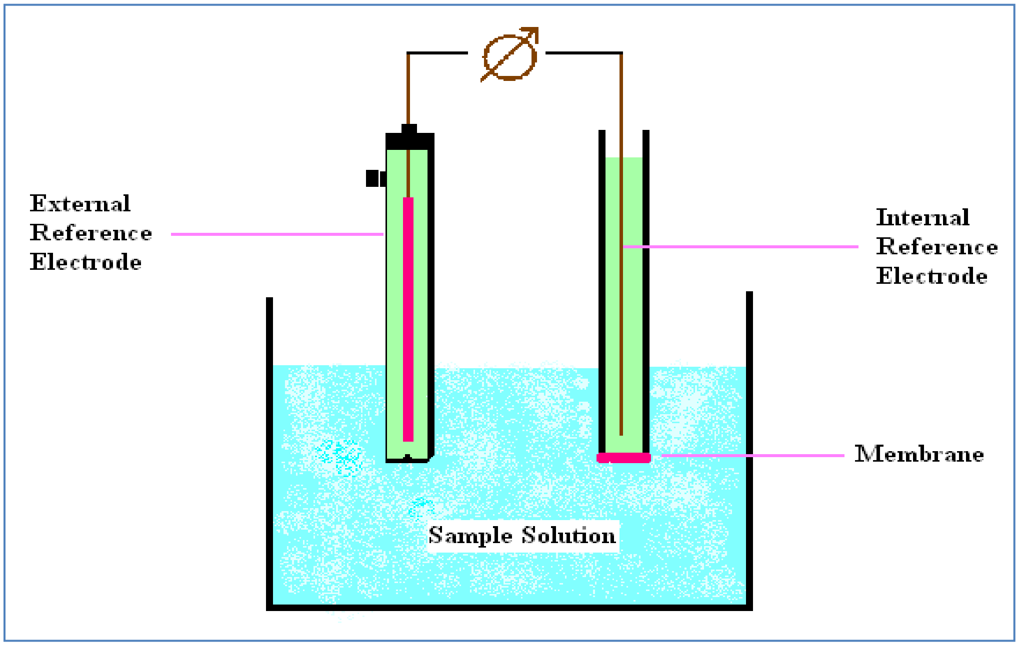
heavy metals. FTIR can be employed for water pollution monitoring, source identification, and evaluating the effectiveness of water treatment processes.

5. FTIR is employed in the identification and characterization of microplastics, which are small plastic particles found in various environmental matrices, including water, soil, sediments, and organisms. FTIR spectra enable the differentiation of different types of plastics, aiding in assessing the extent of microplastic pollution and its potential environmental impacts.
6. FTIR is used to study various environmental processes and transformations. For example, it can be employed to monitor chemical reactions, assess degradation processes of organic compounds, investigate pollutant fate and transport, and study environmental interactions such as adsorption, desorption, and surface reactions.

FTIR is a versatile technique that offers rapid and non-destructive analysis of a wide range of environmental samples. It provides valuable information on the composition and properties of organic and inorganic compounds, aiding in environmental monitoring, pollution assessment, and understanding environmental processes. In addition the FTIR is also used for Quality verification of incoming/outgoing material, Deformulation of polymers, rubbers, and other materials through thermo gravimetric infra-red (TGA-IR) or gas chromatography infra-red (GC-IR) analysis, Microanalysis of small sections of materials to identify contaminants and Analysis of thin films and coatings

11.7. Ion selective electrode

An ion-selective electrode (ISE) is a device used in analytical chemistry to measure the concentration of a specific ion in a solution. It is an electrochemical sensor that responds selectively to a particular ion while ignoring the interference from other ions in the solution. The basic structure of an ion-selective electrode consists of a sensing element and a reference electrode. The sensing element is a membrane that selectively interacts with the target ion. This membrane contains an ionophore, which is a compound that specifically binds to the target ion and facilitates its transport across the membrane. When the ion of interest comes into contact with the membrane, it interacts with the ionophore, causing a change in the electrical potential across the membrane. This potential change is measured against a stable reference electrode, which provides a constant electrical potential. The potential difference between the sensing and reference electrodes is proportional to the logarithm of the ion concentration in the solution. Ion-selective electrodes are commonly used in various applications, such as environmental monitoring, pharmaceutical analysis, clinical diagnostics, and water quality assessment. Some examples of specific ion-selective electrodes include pH electrodes (measuring hydrogen ion concentration), fluoride electrodes, sodium electrodes, potassium electrodes, chloride electrodes, and many others. These electrodes offer several advantages, including high selectivity, sensitivity, and ease of use. They provide a rapid and direct measurement of ion concentrations, eliminating the need for complex sample preparation. However, they do require calibration with standard solutions to obtain accurate results. Overall, ion-selective electrodes play a crucial role in quantitative ion analysis, allowing scientists and researchers to measure specific ions in a solution accurately and efficiently. Ion-selective electrodes (ISEs) are widely used in environmental sample analysis for the measurement of various ions. Ion-selective electrodes are commonly used to assess the quality of air, water sources water and soil. For example, pH electrodes are used to monitor the acidity or alkalinity of water, while electrodes specific to ions like chloride, nitrate, and phosphate can provide information about potential pollution sources, such as industrial discharges or agricultural runoffs.



The assessment of soil fertility, nutrient levels, and potential contamination is also carried out in solid sample. Common ions of interest include potassium, calcium, magnesium, and ammonium Ion-selective electrodes are also valuable tools for monitoring and controlling environmental remediation processes. For instance, during the cleanup of contaminated sites, ion-selective electrodes can be used to measure concentrations of heavy metal ions, such as lead, cadmium, or mercury, in soil or water samples to assess the effectiveness of remediation efforts. It also plays the crucial role in monitoring and controlling wastewater treatment processes. They are used to measure and control the concentrations of various ions, such as pH, chloride, sulfate, and ammonia, to ensure efficient treatment and compliance with environmental regulations. In addition, Ion selective electrodes are used also used to measure the concentrations of ions in marine and aquatic environments. For example, measuring the levels of dissolved oxygen, pH, and salinity using specific electrodes provides valuable information about water quality, ecosystem health, and potential impacts of pollution on aquatic organisms.

Sample preparation

Sample preparation for ion-selective electrode (ISE) analysis of environmental samples, including air, water, and soil, is essential for obtaining accurate and reliable results. The specific sample preparation steps can vary depending on the type of sample and the target ion being analyzed. Here are some general guidelines for sample preparation for ISE analysis in environmental samples:

- **Sample Collection**:

  Collect representative samples of the environmental matrix you want to analyze, such as air, water, or soil. Follow appropriate sampling guidelines and procedures to ensure sample integrity.

- **Sample Filtration**:

  Depending on the sample matrix, filtration may be necessary to remove particulate matter or suspended solids that can interfere with the measurement or clog the electrode. Filtration methods can include using syringe filters or filter papers with suitable pore sizes. Example:

  i. Collect air samples using air sampling pumps equipped with filters. Use filters with appropriate pore sizes to retain the particulate matter and prevent it from entering the ion-selective electrode.
  ii. Collect water samples and filter them using a membrane filter or a filter apparatus to remove suspended solids or particulate matter.

iii. Soil samples may require a suspension or extraction step to prepare a liquid sample for analysis. After suspension, filtration can be performed to remove coarse particles before analysis.

- **Sample Extraction or Preparation:**

  Depending on the sample matrix and the target ion, different extraction or preparation methods may be required to extract or convert the analyte into a suitable form for measurement. Example:

  i. For gaseous ions, the air sample may need to be trapped in a suitable medium, such as an absorbent or a scrubber solution, to convert the gaseous ion into a liquid form for measurement.

  ii. In water sample preparation may involve adjusting the pH, diluting the sample, or performing a specific extraction technique to concentrate the ion of interest.

  iii. Soil samples may require extraction using suitable solvents to extract the target ions from the soil matrix. This can be done through techniques like leaching, extraction with specific reagents, or soil suspension followed by filtration.

- **Calibration Standards:**

  Prepare a series of calibration standards by diluting standard solutions of known ion concentrations. These calibration standards are used to create a calibration curve for quantification.

- **Quality Control:**

  Include blank samples (solvent without ions) and spiked samples (known addition of ions to blanks) as quality control measures to assess and monitor the accuracy and precision of the analysis.

Sample Handling and Storage: Proper storage and preservation of samples are crucial to maintain sample integrity until analysis. Follow appropriate storage conditions and preservation techniques, such as refrigeration, freezing, or the addition of preservatives, as required for the specific sample matrix.

11.7.1. Ion selective electrode for air sampling analysis:

Ion-selective electrodes (ISEs) are primarily designed for the analysis of ions in liquid solutions. However, there are some adaptations and techniques that allow for the use of ion-selective electrodes in air sampling and analysis are described:

- **Gas-Permeable Membrane Electrodes**: Specialized ion-selective electrodes can be equipped with gas-permeable membranes that allow the passage of ions from the gas phase into a liquid phase for analysis. These electrodes can be used to measure certain gaseous ions present in the air, such as carbon dioxide ($\mathrm{CO_2}$) or ammonia ($\mathrm{NH_3}$). The gas molecules diffuse through the membrane and interact with the ionophore in the liquid phase, leading to a measurable potential change.
- **Aerosol Collection and Dissolution:** Another approach is to collect aerosol particles from the air onto a collection surface and subsequently dissolve them in a liquid medium for ion analysis. The resulting liquid can then be analyzed using ion-selective electrodes. For example, this technique can be used to measure ions like sulfate (SO_4^{2-}) or nitrate ($\mathrm{NO_3^-}$) in particulate matter samples collected from the air.
- **Ion Chromatography Coupled with Ion-Selective Detection**: Ion chromatography (IC) is a technique commonly used for the separation and analysis of ions in liquid samples. By coupling IC with ion-selective detection, it is possible to analyze air samples indirectly. In this approach, the air sample is first collected and dissolved in a liquid medium. The resulting solution is then subjected to ion chromatography, where ions are separated based on their properties. The eluent from the ion chromatography column is directed to an ion-selective electrode for specific ion detection.
- **Ion Mobility Spectrometry (IMS):** Although not strictly using ion-selective electrodes, ion mobility spectrometry is an analytical technique that can be employed for air sampling and analysis of ions. In IMS, ions are first ionized in the gas phase, and then their mobility is measured based on their drift time through a drift tube under the influence of an electric field. This technique is commonly used in applications such as detection of volatile organic compounds (VOCs) or explosives in air samples.

It's important to note that air sampling and analysis using ion-selective electrodes require careful considerations and adaptations to ensure accurate measurements. The choice of appropriate collection and sample preparation techniques, as well as electrode design and calibration, is crucial to obtain reliable results. Additionally, it is essential to consider potential interferences from other gases or contaminants present in the air sample and take measures to mitigate their impact on the analysis.

11.7.2. Ion selective electrode for water sampling analysis:

Ion-selective electrodes (ISEs) are widely used for water sample analysis due to their ability to selectively measure specific ions. Here are some common ion-selective electrodes used for water sample analysis:

- **pH Electrode:** pH electrodes are used to measure the acidity or alkalinity of water samples by detecting the concentration of hydrogen ions (H^+). They provide information about the water's level of acidity or alkalinity, which is crucial for various applications, including environmental monitoring, wastewater treatment, and aquatic research.
- **Chloride Ion-Selective Electrode:** Chloride ion-selective electrodes are used to measure the concentration of chloride ions (Cl^-) in water samples. They are valuable in applications such as determining saltwater intrusion, assessing water quality, and monitoring industrial processes that involve chloride-containing compounds.
- **Fluoride Ion-Selective Electrode:** Fluoride ion-selective electrodes are employed to measure the concentration of fluoride ions (F^-) in water samples. They are particularly useful in monitoring drinking water sources to ensure compliance with recommended fluoride levels for dental health or investigating the presence of fluoride in environmental samples.
- **Sodium Ion-Selective Electrode:** Sodium ion-selective electrodes are used to measure the concentration of sodium ions (Na^+) in water samples. They find applications in assessing water salinity, monitoring desalination processes, and studying the impact of sodium on environmental systems.
- **Potassium Ion-Selective Electrode:** Potassium ion-selective electrodes are utilized to measure the concentration of potassium ions (K^+) in water samples. They are valuable in agricultural research, soil analysis, and water quality assessment, as potassium is an essential nutrient for plants and its levels impact crop growth and soil fertility.
- **Calcium Ion-Selective Electrode:** Calcium ion-selective electrodes are employed to measure the concentration of calcium ions (Ca^{2+}) in water samples. They find

applications in assessing water hardness, monitoring calcium levels in aquaculture systems, and studying the impact of calcium on aquatic ecosystems.

- **Ammonium Ion-Selective Electrode:** Ammonium ion-selective electrodes are used to measure the concentration of ammonium ions (NH_4^+) in water samples. They are valuable in monitoring wastewater treatment plants, assessing nutrient levels in surface water, and investigating the impact of ammonium on aquatic organisms.

11.7.3. Ion selective electrode for Soil sampling analysis:

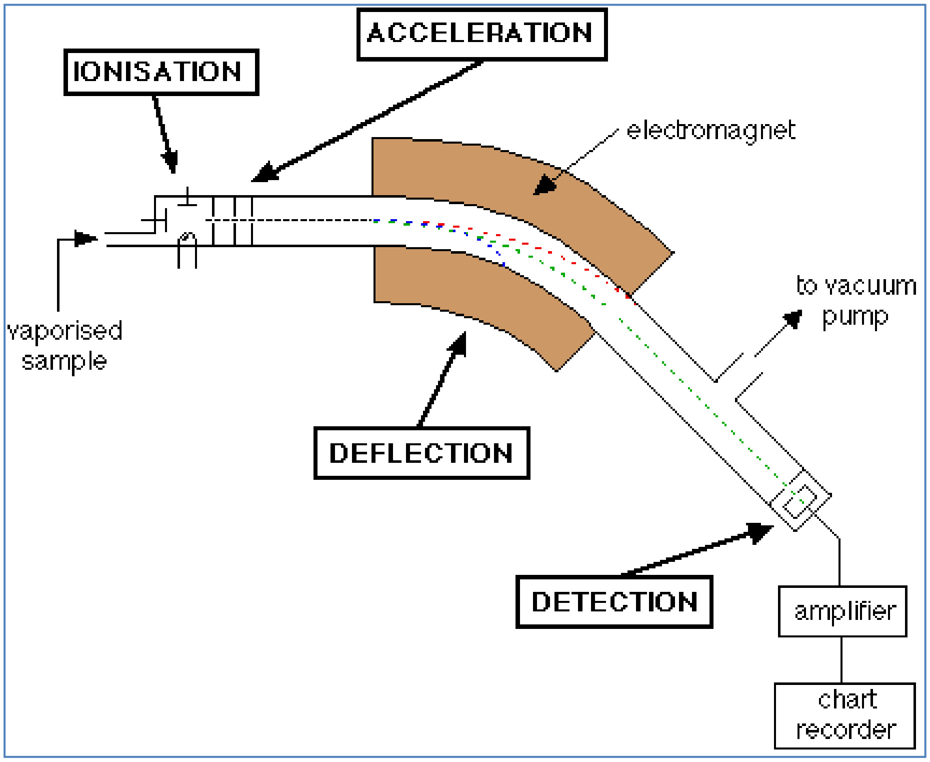
Ion-selective electrodes (ISEs) are commonly used for soil sampling analysis to measure the concentration of specific ions in soil samples. Here are some examples of ion-selective electrodes used for soil analysis:

- **Potassium Ion-Selective Electrode:** Potassium ion-selective electrodes are widely used in soil analysis to measure the concentration of potassium ions (K^+). Potassium is an essential nutrient for plant growth, and its availability in soil impacts crop productivity. These electrodes provide valuable information for optimizing fertilizer application and assessing soil fertility.
- **Calcium Ion-Selective Electrode:** Calcium ion-selective electrodes are employed to measure the concentration of calcium ions (Ca^{2+}) in soil samples. Calcium is important for soil structure and nutrient availability. Monitoring calcium levels helps in assessing soil quality, understanding nutrient cycling, and managing soil amendments.
- **Ammonium Ion-Selective Electrode:** Ammonium ion-selective electrodes are used to measure the concentration of ammonium ions (NH_4^+) in soil samples. Ammonium plays a significant role in soil nitrogen dynamics and nutrient availability for plants. These electrodes aid in studying nitrogen transformations, evaluating fertilizer efficiency, and managing soil nitrogen levels.
- **Nitrate Ion-Selective Electrode**: Nitrate ion-selective electrodes are employed to measure the concentration of nitrate ions (NO_3^-) in soil samples. Nitrate is an essential nutrient for plants but can also be a pollutant when present in excessive amounts. Monitoring nitrate levels helps in optimizing fertilizer application, assessing soil health, and mitigating environmental impacts.

- **pH Electrode:** Although not strictly an ion-selective electrode, pH electrodes are commonly used in soil analysis to measure soil pH, which reflects the soil's acidity or alkalinity. Soil pH is a crucial factor influencing nutrient availability, microbial activity, and plant growth. pH electrodes provide insights into soil fertility and help guide lime or acid amendment recommendations.
- **Chloride Ion-Selective Electrode:** Chloride ion-selective electrodes are used to measure the concentration of chloride ions (Cl^-) in soil samples. Chloride levels in soil can indicate salinity or the presence of chloride-based fertilizers. Monitoring chloride helps assess soil salinity, irrigation management, and potential impacts on plant health.

11.8. Mass spectrometry (MS)

Mass spectrometry (MS) is a powerful analytical technique extensively used in environmental sample analysis for the identification, characterization, and quantification of compounds present in complex matrices. It offers high sensitivity, selectivity, and the ability to provide structural information about the analyzed compounds.



Mass spectrometry involves the ionization of molecules in a sample, followed by their separation based on their mass-to-charge ratio (m/z) and detection. The sample is ionized, typically by techniques such as electron impact ionization (EI), electrospray ionization (ESI), or matrix-assisted laser desorption/ionization (MALDI). The resulting ions are then accelerated, separated based on their m/z values using electric or magnetic fields, and detected to generate mass spectra.

A typical mass spectrometer consists of three main components: an ion source, a mass analyzer, and a detector. Different types of mass analyzers are used, including quadrupole, time-of-flight (TOF), ion trap, and magnetic sector analyzers. The choice of analyzer depends on the desired application and performance requirements. The detector records the ion signals, and the data is processed to generate mass spectra, which represent the distribution of ions based on their m/z values. Mass spectrometry is employed in a wide range of environmental sample analysis applications such as

1. Analysis of organic pollutants in water, soil, sediment, and air samples, such as pesticides, pharmaceuticals, industrial chemicals, and metabolites.
2. Detection and identification of volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) in air and emission samples.
3. Monitoring of emerging contaminants, including endocrine disruptors, microplastics, and per- and polyfluoroalkyl substances (PFAS).
4. Isotope ratio analysis to investigate the origin, transport, and transformation of environmental contaminants.
5. Analysis of biomarkers and metabolites for environmental and human health studies.
6. Screening and confirmation of contaminants in food, beverages, and consumer products.
7. Mass spectrometry provides invaluable insights into the identity, structure, and concentration of compounds in environmental samples. Its sensitivity, selectivity, and versatility make it a critical tool in environmental monitoring, pollution assessment, source identification, and risk evaluation.

11.9. Total organic carbon analysis

Total Organic Carbon (TOC) analysis is a widely used technique in environmental sample analysis for the measurement of the total amount of carbon present in organic compounds within a sample. It provides valuable information about the organic content and the potential for organic pollution in various environmental matrices. Here's an overview of TOC analysis: TOC analysis is based on the principle of oxidizing organic carbon compounds present in a sample to carbon dioxide (CO_2) through combustion or chemical oxidation methods. The evolved CO_2 is then quantified by various detection methods, typically non-dispersive infrared (NDIR) detection or coulometric detection.

TOC analyzers consist of several key components, including a sample introduction system, an oxidation reactor, a CO_2 detection system, and data analysis software. The sample introduction system enables the efficient transfer of the sample to the oxidation reactor. The oxidation reactor contains a catalyst or an oxidizing agent that converts the organic carbon to CO_2. The CO_2 detection system measures the concentration of CO_2 produced during the oxidation process, and the data analysis software calculates and reports the TOC concentration in the sample. Sample preparation for TOC analysis depends on the nature of the sample. Liquid samples, such as water, are typically filtered to remove particulate matter before analysis. Solid samples, such as soil or sediment, may require extraction or digestion methods to release the organic carbon. The prepared sample is then introduced into the TOC analyzer for analysis. TOC analysis has diverse applications in environmental sample analysis such as:

1. Assessment of water quality in natural water bodies, drinking water, and wastewater.
2. Monitoring organic pollution levels in industrial effluents and environmental samples.
3. Evaluation of soil and sediment quality for agricultural and environmental studies.
4. Characterization of organic matter content in soils, sediments, and compost.
5. TOC analysis provides a rapid, sensitive, and non-selective measurement of the total organic carbon content in a sample. It is a valuable tool for assessing environmental contamination, monitoring pollution levels, evaluating treatment processes, and studying organic carbon dynamics in various environmental systems.

11.10. Summary

Instrumental techniques play a crucial role in environmental sample analysis, enabling scientists and researchers to obtain accurate and precise measurements of various parameters. Atomic spectroscopy techniques, including atomic absorption spectroscopy (AAS) and inductively coupled plasma-optical emission spectroscopy (ICP-OES) or inductively coupled plasma-mass spectrometry (ICP-MS), are employed for the analysis of inorganic elements and metals in environmental samples. These techniques are useful in assessing soil and water quality, monitoring heavy metal contamination, and studying elemental composition in biological samples. XRF is employed for the elemental analysis of solid and liquid samples. It can provide information on the elemental composition of samples, aiding in the analysis of soils, sediments, rocks, and environmental samples containing heavy metals. FTIR spectroscopy is used for the identification and characterization of organic and inorganic compounds based on their absorption of infrared radiation. It finds applications in the analysis of pollutants, polymers, organic compounds, and functional groups in environmental samples. Ion-selective electrodes (ISEs) are valuable tools for the selective measurement of specific ions in liquid samples. They find applications in environmental analysis for the measurement of ions such as pH, chloride, fluoride, nitrate, and ammonium. These instrumental techniques, along with others not mentioned here, provide researchers with a wide range of tools for environmental sample analysis. They enable the detection, quantification, and characterization of various pollutants, contaminants, and parameters, helping to understand and monitor the environmental health and quality.

11.11. Terminal questions

Q.1. What the instrumental techniques? Discuss the different techniques used in environmental sample analysis.

Answer:--

Q.2. What are AAS? Discuss it principle and application in environmental sample analysis.

Answer:--

Q.3. Discuss the principle, instrumentation of inductive couple plasma emission spectroscopy (ICPES).

Answer:--

Q.4. Discuss the role of fluorescence spectroscopy for water sample analysis.

Answer:--

Q.5. Discuss about ion selective electrode and its role in air water and soil analysis.

Answer:--

Q.6. What is Fourier transforms infrared spectroscopy (FTIR)? Discuss it role in environmental sample analysis.

Answer:--

11.12. Further suggested Readings

1. Environmental Science, Tom Theis and Jonathan Tomkin, OpenStax CNX, National Digital Library of India.
2. Textbook for Environmental Studies, ErachBharucha.
3. Environmental Science, Subhas ChandraSantra, new central book agency, 3rd Edition, 2011.
4. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.
5. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd.
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Unit-12.: Air prevention and control of pollution

Contents

12.1. Introduction

Air pollution is a significant global environmental issue that poses serious threats to human health, ecosystems, and the overall quality of life. It refers to the contamination of the air by harmful substances, including pollutants such as gases, particulate matter, and chemicals, which are released into the atmosphere through various human activities and natural processes. Prevention and control of air pollution involve implementing measures to reduce and mitigate the emission of pollutants and to protect the air quality. Governments and regulatory bodies establish emission standards and regulations that set limits on the amount of pollutants that industries, vehicles, and other emission sources can release into the atmosphere. Compliance with these standards is enforced through monitoring, inspections, and penalties for non-compliance. One of the most effective ways to reduce air pollution is to shift from fossil fuels to cleaner and renewable energy sources such as solar, wind, and hydroelectric power. This transition involves promoting the use of electric vehicles, supporting renewable energy technologies, and phasing out the use of coal and other high-polluting fuels. Vehicles are a major source of air pollution, especially in urban areas. Measures such as implementing emission standards for vehicles, promoting the use of public transportation, encouraging the adoption of electric and hybrid vehicles, and improving fuel quality can help reduce vehicle emissions and improve air quality. Proper waste management practices are essential to prevent the release of pollutants into the air. Encouraging recycling, composting, and waste-to-energy technologies can help reduce the amount of waste that ends up in landfills and incinerators, thereby reducing air pollution from these sources. Planting trees and creating green spaces in urban areas can help improve air quality by absorbing pollutants, reducing heat island effects, and providing oxygen.

Trees act as natural filters and help remove pollutants from the air. Educating the public about the causes and impacts of air pollution is crucial for prevention and control efforts. Promoting awareness campaigns, providing information on sustainable practices, and encouraging individuals to make environmentally conscious choices can lead to positive changes in behavior and lifestyle. It is important to note that air pollution is a complex and multifaceted issue, requiring a holistic and integrated approach involving cooperation among governments, industries, communities, and individuals. By implementing these prevention and control measures, we can work towards reducing air pollution and creating a cleaner and healthier environment for future generations.

Objectives

- To discuss the air prevention and control of pollution act 1981
- To discuss the air act amended by amendment 1987
- To discuss the motor vehicle act,1988
- To discuss the environment (protection) act 1986, and rules 1986
- To discuss the national green tribunal act 2010

12.2. Air (prevention & control of pollution) act 1981

In 1981, the prevention and control of air pollution was already recognized as an important environmental issue. Several measures were in place to address this problem. In the United States, the Clean Air Act of 1970 was already in effect in 1981. This legislation aimed to regulate and reduce air pollution by establishing air quality standards, limiting emissions from industrial sources, and setting emission standards for motor vehicles. Industries were required to adopt emission control technologies to reduce the release of pollutants into the atmosphere. This included the use of scrubbers, filters, and other pollution control devices to capture and treat emissions before they were discharged.

About Air (Prevention and Control of Pollution) Act, 1981

Air pollution has reached alarming proportions around the globe and India has also been severely afflicted by air pollution. Greenpeace India, in its report published in 2017 has reported that around 1.2 million people die in India annually on account of air pollution related diseases. As per the report, air pollution costs around 3% of India’s Gross Domestic Product. Assessment by Greenpeace of India’s 168 cities across 24 states shows that none of the cities in India can claim to have clean air by WHO standards.

An Act to provide for the prevention, control and abatement of air pollution, for the establishment, with a view to carrying out the aforesaid purposes, of Boards, for conferring on and assigning to such Boards powers and functions relating thereto and for matters connected therewith. The United Nations Conference on Human Environment held at Stockholm in June 1972 decided to take appropriate steps for preservation and protection of natural resources of the earth including Air. India participated in this conference. Stockholm conference is watershed in International Environmental law and it affected Indian nation also. The Constitution (Forty Second Amendment) Act, 1976 inserted Article 48A in the Indian Constitution which provides that State shall endeavour to protect and improve the environment and to safeguard the forests and wild life of the country. The amendment also included Fundamental duties in the Constitution.vi Once, Indian nation decided to implement the decisions taken at Stockholm conference, it enacted Water Act, 1974 and Air (Prevention and Control of Pollution) Act, 1981 (hereinafter referred to as Air Act). Air Act was enacted under Article 253 of the Constitution.vii The Act came into force on 16th May 1981 and it applies to whole of India.

Objectives of Air (Prevention and Control of Pollution) Act, 1981

The Air (Prevention and Control of Pollution) Act, 1981 seeks to prevent, control, and reduce air pollution in order to protect the quality of the environment.

Boards Set up under this Act

There are certain central and state boards set up under this act for the prevention and control of air pollution.

Central Pollution Control Board (CPCB)

It is a statutory organisation founded in 1974 under section 3 of the Water (Prevention and Control of Pollution) Act, 1974. The Air Act adopts integrated and comprehensive approach to tackle environmental pollutionxiii and accordingly, the Act provides that Central Board constituted under the Water Act, shall have the powers and shall perform the functions assigned to the Central Board under the Air Act alsoxiv. Therefore, the Central Board constituted under the Water Act shall be the Central Board for the purposes of Air Act also and it shall perform functions of State Board in Union Territories apart from performing the functions of Central Board.

State Pollution Control Boards constituted under section 4 of Act 6 of 1974 to be State Boards under this Act

In any State in which the Water (Prevention and Control of Pollution) Act, 1974 (6 of 1974), is in force and the State Government has constituted for that State a State Board for the Prevention and Control of Water Pollution under section 4 of that Act, such State Board shall be deemed to be the State Board for the Prevention and Control of air Pollution constituted under section 5 of this Act and accordingly that State Board for the Prevention and Control of Water Pollution shall, without prejudice to the exercise and performance of its powers and functions under that Act, exercise the powers and perform the functions of the State Board for the Prevention and Control of Air Pollution under this Act.] The State Boards have the task of implementing the provisions of the Air Act. Like Water Act, State Boards under the Air Act also have the attributes of a Body Corporate, capacity to sue and be sued, capacity to hold, acquire and dispose of property, perpetual succession, common seal etc. Composition of State Pollution Control Boards is as under:

i. The Chairman of the Board shall be either full time or Part-time Chairman to be nominated by the State government. To be eligible to be appointed as Chairman, the person shall possess special knowledge or practical experience in matters relating to environmental protection.

ii. Not more than five Government officials as representative of the State government. These officials are required to be nominated by the State government.

iii. Not more than five persons from amongst the local authorities functioning with the States. These members are also required to be nominated by the State government.

iv. State government is required to nominate non-officials (not more than three) to represent the interests of Agriculture, fishery, industry or trade or any other interest which the State government believes that it should also be represented in the Board.

v. Two persons representing Companies or Corporations owned or controlled by the State government. These persons are also to be nominated by the State government. (vi)State government is required to nominate one Full time member-secretary. Member Secretary is required to possess administrative experience and practical experience in relation to environmental protection.

The perusal of the above makes it clear that the composition of State Board under the Air Act is almost similar to the composition of State Board under the Water Act. It is further clarified that after constitution of the State Board under Air Act, if any State adopts Water Act and constitutes State Board under the Water Act, State Board constituted under Air Act shall be dissolved

The tenure of members of the Board is three years. However, the tenure of official members shall come to an end as soon as they cease to hold the office under the government by virtue of which they were appointed. Similarly, members appointed to represent Companies/Corporations owned or controlled by the State government or the Local authority, shall cease to be members of the Board as soon as they cease to be the officers of the Company/Corporation or the Local authority. If any member is absent from three consecutive meetings without sufficient reason, he shall be deemed to have vacated the office of the State Board. A member may be removed from office after giving him a reasonable opportunity of being heard. Member may also resign from office before the expiry of his tenure.Members is eligible for re-nomination.

If any person suffers from the following disqualifications, he shall not be eligible to appointed as the member of State Board and if he is the member, he shall cease to be member of the State Board: i) Declared as in insolvent; ii) Declared as person of unsound mind; iii) Convicted of an offence involving moral turpitude; iv) Convicted of any offence under the Air Act;

Functions of State Boards

In addition to the functions under the Water Act, State Boards are required to perform the following functions; i) To collect and disseminate information pertaining to air pollution; ii) To plan and execute programme for the prevention, control, abatement and eradication of air pollution; iii) To advise the State government regarding matters pertaining to air pollution; iv) To inspect air control equipment manufacturing plants and to issue appropriate directions concerning prevention, control and abatement of air pollution; v) To co-ordinate and collaborate with CPCB in organizing training of persons engaged in connection with prevention, control and abatement of air pollution; vi) To inspect air pollution control areas, assess the quality of air and to take steps for prevention, control and abatement of air pollution; vii)To lay down, in consultation with CPCB and having regard to ambient air quality standards prescribed by CPCB, standards for emission of air pollutants into the atmosphere by industrial plants and vehicles; To establish or recognize a laboratory in connection with functions under the Air Act; ix) To advise the government regarding suitability of any premises for the purposes of carrying on of any industry likely to cause air pollution; x) To perform such other functions as may be prescribed from time to time

Prevention and Control of Air Pollution

Chapter IV of Air Act, containing sections 19-31, enacts provisions for prevention and control of air pollution. The Air Act contains both remedial and preventive measures for prevention, control and abatement of air pollution. A brief detail of such provisions is given hereinafter.

1) For the purposes of the Air Act, State government, in consultation with State Board, can declare certain areas to be air pollution control areas by notification in the official gazette. It can also in the same manner alter such areas, add or extend that area and declare new area to be air pollution control area.
2) State government can also prohibit, after consultation with the State Board, use of any fuel which causes air pollution or is likely to cause air pollution, in the air pollution control area. The notification prohibiting use of any fuel shall give atleast three months before prohibition becomes operational.
3) For control of air pollution in air pollution control areas, State government can prescribe and approve appliances for use in premises situated in air pollution control areas. Such notification shall be issued after consultation with the State Board.
4) For control of air pollution and to prevent the air pollution, State government after consultation with the State Board can ban/prohibit burning of any material in the air pollution control areas which in the opinion of the government is causing or likely to cause air pollution.
5) State government after consultation with the State Board can issue instructions to Vehicle Registration authorities under the Motor Vehicles Act, 1988 for ensuring compliance with

the emission standards fixed and notified by the State Boards. Such authorities are bound by the directions/instructions issued under this Act. Section 110 of Motor Vehicles Act also empowers the Central government to issue directions regarding emission of smoke, visible vapour, sparks, ashes, reduction of noise caused by vehicles and standards of emission of air pollutants.

6) Air Act bars all persons operating any industrial plant in an air pollution control area from discharging or emitting air pollutants in excess of the prescribed limits. Before the amendments of 1987, the bar was only with respect to industries specified in the first schedule. 12 Environmental Sciences Environmental Law and Policies Air (Prevention and Control of Pollution) Act, 1981 The Amendment Act of 1987 extended the bar to all industrial plants and omitted First Schedule.

7) Air Act bars a person from operating any industrial plant in an air pollution control area except with the consent of State Board. Thus, Air Act requires the consent of the State Board before an industrial plant can be established in an air pollution control area. If the industrial plant was already established and working in an area which has been later declared as an air pollution control area, in such a case, it is required to file application for consent within three months. If such an application has been filed along with prescribed fee within three months, the industrial plant can continue its operations till the disposal of the application

Appeals

Any person, who is dissatisfied with the decision/order of the State Board under the Air Act, can file an appeal before the designated appellate authority within 30 days of the date of the order. The appellate authority has the power to condone the delay and accept the appeal even after the lapse of 30 days, if it is satisfied that there was sufficient cause for the delay. Appeal shall be accompanied by prescribed fee. Appellate authority may be single member or three members and it is required to dispose of the appeal as expeditiously as possible. Civil Courts jurisdiction to entertain any matter on which appeal can be filed before the appellate authority has been barred under the Air Act.

Offences and Penalties

Chapter VI of the Air Act, containing sections 37-46, deals with penalties and procedure. Offences and penalties prescribed under the Air Act are given hereinafter.

1) Punishment of mandatory imprisonment for a term of one and half years but which may extend upto six years and fine can be imposed for the following defaults.
    a. If any person does not obtain the pervious consent of the State Board before establishing any industrial plant in an air pollution control area or
    b. In case of an industry already established in the area before declaration of that area as air pollution control area, does not apply for such consent within three months or
    c. Any person operating an industrial plant in pollution control area and emitting air pollutants in excess of the standards laid down by the Board or
    d. Any person violating directions of the State Board issued under section 31A
2) Any person guilty of the following acts/defaults/failures shall be punished with imprisonment which may extend upto three months or with fine extendable upto 10000 Rupees or with both 18 Environmental Sciences Environmental Law and Policies Air (Prevention and Control of Pollution) Act, 1981
    a. Destroying, pulling down, removing, injuring, defacing any pillar, post, notice etc. fixed in the ground or any other matter put up or inscribed etc by the State Board or under its authority or
    b. Obstructing any person in the performance of his functions entrusted by the Board under the Air Act or
    c. Damaging any work or property belonging to the Board or
    d. Failure to furnish information required by the Board or the officers/persons authorised by the Board or
    e. Failure to intimate the Board about the emission of air pollutants in excess of the prescribed standards or failure to inform about the accident or unforeseen circumstances likely to cause emission of air pollutants in excess of the prescribed limits or
    f. Making of false statement or g. Contravention of any other provision of the Air Act for which no specific penalty has been prescribed.

12.3. Air act amended by amendment 1987

In 1987, the United States made significant amendments to the Clean Air Act, a key environmental legislation aimed at addressing air pollution. The amendments made several important changes and introduced new provisions to further enhance air pollution prevention and control. Here are some key aspects of the Clean Air Act amendments of 1987:

Stricter Air Quality Standards: The amendments required the Environmental Protection Agency (EPA) to establish more stringent national ambient air quality standards (NAAQS) for pollutants deemed harmful to public health and the environment. This included setting standards for pollutants such as particulate matter, ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, and lead.

New Emission Reduction Measures: The amendments introduced new provisions to control and reduce emissions from various sources. They required the EPA to establish technology-based emission standards for major industrial sources, known as New Source Performance Standards (NSPS), which aimed to limit emissions during the construction and operation of new or modified facilities.

Acid Rain Program: One of the significant additions through the amendments was the Acid Rain Program. It established a cap-and-trade system to reduce sulfur dioxide (SO2) and nitrogen oxide (NOx) emissions from power plants, which were major contributors to acid rain. This market-based approach allowed power plants to trade emission allowances, incentivizing emission reductions in a cost-effective manner.

Stratospheric Ozone Protection: The amendments included provisions to address the depletion of the ozone layer. They mandated the phase-out of ozone-depleting substances, such as chlorofluorocarbons (CFCs), through the establishment of a regulatory program. The EPA was given authority to regulate the production, use, and disposal of these substances.

Mobile Source Emissions: The amendments focused on reducing emissions from motor vehicles and introduced measures to control pollution from mobile sources. This included the requirement for stricter emission standards for cars, trucks, and other vehicles, as well as the implementation of onboard diagnostic systems and emission control technologies.

Enforcement and Penalties: The amendments strengthened enforcement provisions, allowing the EPA to impose penalties on non-compliant facilities and individuals. Civil and criminal penalties were increased to deter violations of the Clean Air Act.

Research and Development: The amendments emphasized the importance of research and development in addressing air pollution. Funding was allocated for studies on emerging pollutants, the development of cleaner technologies, and the assessment of the health and environmental impacts of air pollution. These amendments to the Clean Air Act in 1987 aimed to further reduce air pollution, protect public health, and preserve the environment. The provisions introduced through these amendments have played a crucial role in shaping air pollution control efforts in the United States.

12.4. Air rule 1982

The key legislation in India concerning air pollution control is the Air (Prevention and Control of Pollution) Act of 1981. This act was enacted to prevent, control, and abate air pollution in India. It provides a legal framework for the establishment of central and state pollution control boards, which are responsible for implementing and enforcing air pollution control measures. The Air Act of 1981 empowers the central and state pollution control boards to take measures for the prevention, control, and abatement of air pollution. These measures include:

Regulation of Emissions: The act empowers the pollution control boards to prescribe emission standards for industries, vehicles, and other sources of air pollution. It sets limits on the amount of pollutants that can be emitted into the air.

Issuance of Consent: Industries and other activities that release pollutants into the air are required to obtain consent from the pollution control boards. This consent ensures that industries comply with emission standards and implement necessary pollution control measures.

Monitoring and Surveillance: The act provides provisions for monitoring air quality and emissions through ambient air quality monitoring stations and stack emission monitoring. This helps in assessing the air pollution levels and identifying sources of pollution.

Inspection and Enforcement: The pollution control boards have the authority to conduct inspections of industries and other pollution sources to ensure compliance with emission standards and other pollution control measures. Non-compliance can result in penalties and legal action.

Public Awareness and Participation: The act encourages public participation in air pollution control efforts. It allows for the public to be informed and involved in matters related to air pollution control, including the submission of complaints and suggestions.

It is worth mentioning that since the Air Act of 1981, there have been several amendments and additional regulations implemented to strengthen air pollution control in India. These include the introduction of specific rules and regulations for vehicular emissions, industrial emissions, and the regulation of specific pollutants such as particulate matter and sulfur dioxide.

12.5. Motor vehicle act,1988

The Indian Motor Vehicles Act of 1988 is a significant legislation in India that governs various aspects related to motor vehicles, road safety, and transportation. It replaced the previous Motor Vehicles Act of 1939 and has been amended several times since its inception. Here are some key features and provisions of the Indian Motor Vehicles Act of 1988:

Licensing of Drivers: The Act lays down the provisions for the issuance of driving licenses, including the eligibility criteria, application process, and the types of licenses for different vehicle categories.

Vehicle Registration: The Act provides guidelines for the registration of motor vehicles. It specifies the requirements for obtaining vehicle registration certificates and the responsibilities of vehicle owners regarding registration, renewal, and transfer of ownership.

Traffic Rules and Regulations: The Act establishes rules and regulations for traffic control and road safety. It covers aspects such as speed limits, traffic signals, lane discipline, overtaking rules, and the use of safety equipment like seat belts and helmets.

Motor Vehicle Taxes and Fees: The Act defines the framework for levying and collecting taxes, fees, and penalties related to motor vehicles. It includes provisions for road tax, vehicle fitness certificates, permits, and fines for traffic violations.

Insurance: The Act mandates motor vehicle insurance to ensure financial protection in case of accidents and damages. It specifies the types of insurance coverage required and the responsibilities of vehicle owners and insurers.

Motor Vehicle Safety Standards: The Act empowers the central government to establish and enforce safety standards for motor vehicles. It covers aspects such as vehicle construction, design, equipment, and emission norms.

Offenses and Penalties: The Act lists various offenses related to motor vehicles and prescribes penalties for violations. This includes offenses such as driving under the influence of alcohol or drugs, overspeeding, dangerous driving, and not following traffic rules.

Motor Vehicle Taxes and Fees: The Act defines the framework for levying and collecting taxes, fees, and penalties related to motor vehicles. It includes provisions for road tax, vehicle fitness certificates, permits, and fines for traffic violations.

It's important to note that the Indian Motor Vehicles Act of 1988 has been amended several times to address emerging challenges, enhance road safety measures, and align with changing transportation dynamics. Amendments have been made to introduce provisions for electric vehicles, road safety initiatives, and the integration of digital technology for licensing, registration, and enforcement.

12.6.The environment (protection) act 1986, and rules 1986

The Environmental Protection Act (EPA) of 1986 is a crucial legislation in India that provides the framework for environmental protection and the prevention and control of pollution. The act was enacted to address various environmental issues, including air and water pollution, hazardous waste management, and conservation of natural resources. Here are some key features and provisions of the Environmental Protection Act of 1986:

Objective: The main objective of the act is to protect and improve the environment and safeguard human health and well-being. It aims to ensure sustainable development and promote the principles of environmental justice.

- **Overview:** The Environment (Protection) Act (EPA) was enacted in 1986 with the objective of providing the protection and improvement of the environment.
    - It empowers the Central Government to establish authorities charged with the mandate of preventing environmental pollution in all its forms and to tackle specific environmental problems that are peculiar to different parts of the country.

  - The Act is one of the most comprehensive legislations with a pretext to protection and improvement of the environment.
- **Background:**
- The roots of the enactment of the EPA lies in the United Nations Conference on the Human Environment held at Stockholm in June, 1972 (Stockholm Conference), in which India participated, to take appropriate steps for the improvement of the human environment.
  - The Act implements the decisions made at the Stockholm Conference.
- **Constitutional Provisions:**
  - The EPA Act was enacted under Article 253 of the Indian Constitution which provides for the enactment of legislation for giving effect to international agreements.
  - Article 48A of the Constitution specifies that the State shall endeavour to protect and improve the environment and to safeguard the forests and wildlife of the country.
  - Article 51A further provides that every citizen shall protect the environment.
- Coverage: The Act is applicable to the whole of India including the state of Jammu & Kashmir.

Salient Features of the EPA Act

- Powers of the Central Government: The Central Government shall have the power to take all such measures as it deems necessary or expedient for the purpose of protecting and improving the quality of the environment in coordination with the State Governments.
  - The Central government is also empowered to:
    - Plan and execute a nation-wide programme for the prevention, control and abatement of environmental pollution.
    - Lay down standards for the quality of environment in its various aspects.
    - Lay down standards for emission or discharge of environmental pollutants from various sources.
    - The restriction of areas in which any industries, operations or processes or class of industries, operations or processes shall/ shall not be carried out subject to certain safeguards.

  - The Central Government may appoint officers under this Act for various purposes and entrust them with the corresponding powers and functions.
  - The central government as per the Act has the power to direct:
    - The closure, prohibition or regulation of any industry, operation or process.
    - The stoppage or regulation of the supply of electricity or water or any other service.
- Restriction on Pollutant Discharge: No individual or organisation shall discharge/emit or permit to discharge/emit any environmental pollutant in excess of the prescribed standards.
- Compliance with Procedural Safeguards: No individual shall handle or shall be caused to handle any hazardous substance except in accordance with the procedure and without complying with the safeguards, as prescribed.
- Powers of Entry and Inspection: Any person empowered by the Central Government shall have a right to enter (with the assistance deemed necessary) at any place:
  - For the inspection of compliance of any orders, notifications and directions given under the Act.
  - For the purpose of examining (and if required seizing) any equipment, industrial plant, record, register, document or any other material object may furnish evidence of the commission of an offence punishable under this Act.
- **Establishment of Environmental Laboratories:** The Central Government, as per the Act, is entitled to:
  - Establish environmental laboratories.
  - Recognise any laboratory or institute as environmental laboratories to carry out the functions entrusted to such a laboratory.
    - The Central Government is also entitled to make rules specifying the functions of environmental laboratories.
- **Appointment of Government Analyst:** A Government Analyst is appointed by the Central Government for the analyzing the samples of air, water, soil or other substance sent to a recognized environmental laboratory.

- **Penalties for Offences:** Non-compliance or Contravention to any of the provisions of the Act is considered as an offence.
  - Any offences under the EPA are punishable with the imprisonment of upto five years or a fine upto one lakh rupees or both.
- **Offences by Companies:** If an offence under this Act is committed by a company, every person directly in charge of the company, at the time of the commitment of offence, is deemed to be guilty unless proven otherwise.
- **Offences by Government Departments:** If an offence under this Act has been committed by any Department of Government, the Head of the Department (HoD) shall be deemed to be guilty of the offence unless proven otherwise.
  - Any officer, other than HoD, if proven guilty, shall also be liable to be proceeded against and punished accordingly.
- **Cognizance of offences:** No Court shall take cognizance of any offence under this Act except on a complaint made by:
  - The Central Government or any authority on behalf of the former.
  - A person who has approached the Courts after a 60-day notice has been furnished to the Central Government or the authority on its behalf.

Drawbacks of the Act

- India’s forest cover is shrinking at a rapid rate. As forest plays a vital role in the resources of the nation, it gets exploited by villagers in need to fuel corrupt officials, greedy forest contractors etc.
- A well-meant yet strict forest bill failed to get people’s support. The main two reasons behind the failure of the forest bill were that it prohibited the usage of any of the products of forests by the tribals. The products included leaves, fruits etc. Another reason for the disappointment was that this bill changed forest officers into judges and executioners simultaneously.
- Regulatory/ enforcing manpower in regulatory agencies is less than required as compared to the ever-growing number of industries.
- The shortfall of required technical skills/ knowledge as needed for enforcement of regulation.
- Aversion to change/ attitudinal difficulties.

- One of the major drawbacks of environmental protection act 1986 is the limitation is financial facilities. Enough resources of money are needed to implement the bare act.

Basic Rules of the Environment Protection Act 1986

- The standard for emission or discharge of pollutants from various commercial plants, processes or operation should be as per the specified guidelines mentioned from schedule 1 to schedule 5. The state government can also be more specific about the standards.
- Soil, water or any sample was taken for critical analysis should be sent to the Environment laboratory by registered post/ special messenger by the Central Government/ officer in charge.
- The result of the critical analysis should be recorded in For 3 in triplicate and must be signed by the Government Analyst. This should also be sent to the officer from whom the sample has been received.
- The Central Government of India may take into consideration various factors for restricting, prohibiting the location of commercial plants and allowing operation in different places.

Key not feature of EPA

Environmental Impact Assessment (EIA): The act introduced the requirement of conducting an Environmental Impact Assessment (EIA) for certain developmental projects. The EIA process assesses the potential environmental impacts of proposed projects before they are granted clearance, helping to mitigate adverse environmental consequences.

Pollution Control Boards: The act provides for the establishment of central and state pollution control boards. These boards are responsible for enforcing pollution control measures, granting consents and permits, conducting inspections, and taking legal action against non-compliant industries.

Polluter Pays Principle: The act incorporates the "polluter pays" principle, which means that the polluting industries or activities are responsible for bearing the costs of preventing, controlling, and mitigating pollution.

Hazardous Substances and Wastes: The act includes provisions for the handling, storage, and management of hazardous substances and hazardous wastes. It sets guidelines for the proper treatment, transportation, and disposal of such substances to prevent adverse impacts on the environment and human health.

Environmental Standards: The act empowers the central government to establish environmental standards for various pollutants, emissions, and effluents. These standards are implemented and enforced by the pollution control boards to ensure the protection of the environment and human health.

Penalties and Offenses: The act prescribes penalties for violations of environmental laws and regulations. It includes provisions for monetary fines, imprisonment, or both for offenses related to environmental pollution, non-compliance with environmental standards, or unauthorized handling of hazardous substances.

Along with the Environmental Protection Act of 1986, the central government has also issued the Environmental Protection Rules in 1986. These rules provide further details and guidelines for the implementation of the act, specifying procedures, forms, and reporting requirements for various environmental aspects.

It is important to note that the Environmental Protection Act and its associated rules have undergone subsequent amendments and updates to align with emerging environmental challenges and international commitments. These amendments have further strengthened environmental regulations and expanded the scope of environmental protection efforts in India.

12.7. The national green tribunal act 2010

The National Green Tribunal (NGT) is a specialized judicial body in India that was established to handle cases related to environmental protection and conservation. The National Green Tribunal (NGT) Act of 2010 is a significant legislation in India that established the National Green Tribunal as a specialized judicial body for effective and expeditious disposal of environmental disputes and matters related to environmental protection and conservation. Here are the key characteristics and examples of the NGT Act:

The National Green Tribunal, often referred to as the NGT, was established in India on October 18, 2010, under the National Green Tribunal Act, 2010. It is a specialized judicial body that deals with environmental disputes and concerns. The NGT's creation was a significant step in addressing environmental issues, as it provides a dedicated forum for individuals and organizations to seek legal remedies for environmental violations.

Jurisdiction: The NGT has jurisdiction over matters related to the prevention and control of environmental pollution and the conservation of natural resources. It hears cases and disputes arising from violations of environmental laws and regulations, and its decisions are binding.

Powers and Functions: The NGT has powers and functions similar to a civil court. It has the authority to hear and decide cases, issue orders, award compensation, and enforce its decisions. The tribunal has the power to take suo moto cognizance of matters related to environmental issues.

Appellate Authority: The NGT Act provides for appeals to be made to the Supreme Court of India against the decisions of the NGT. This ensures the availability of a higher judicial review for cases decided by the tribunal.

Time-bound Proceedings: The NGT Act mandates time-bound proceedings to ensure the expeditious disposal of environmental disputes. It aims to provide quick and effective remedies in cases of environmental violations or harm.

Environmental Compensation: The NGT has the authority to award compensation to victims of environmental damage or pollution. It can direct polluters to pay compensation for environmental harm caused by their activities.

Environmental Clearance and Appeals: The NGT hears appeals against decisions and orders related to environmental clearances for projects and activities that may have environmental implications. It provides a platform for stakeholders to challenge and seek remedies for decisions made by regulatory authorities.

Public Participation: The NGT Act encourages public participation in environmental matters. It allows individuals, non-governmental organizations, and other stakeholders to file cases and present their grievances or concerns related to environmental issues.

Key Features of the National Green Tribunal:

1. **Specialized Jurisdiction:** The NGT has exclusive jurisdiction over matters related to environmental protection and conservation. It can hear cases dealing with a wide range of

environmental issues, including air and water pollution, deforestation, industrial waste, and biodiversity conservation.

2. **Pan-India Presence:** The NGT has regional benches located in various parts of the country, ensuring accessibility to justice for people across India. The principal bench is located in New Delhi, and there are zonal benches in Chennai, Pune, and Kolkata.
3. **Expertise:** The NGT is composed of expert members with backgrounds in environmental science, law, and other relevant fields. These experts bring a deep understanding of environmental issues to the tribunal's proceedings, ensuring informed and specialized decisions.
4. **Cost-Effective Remedies**: The NGT aims to provide a cost-effective and speedy resolution to environmental disputes. It allows for relatively quicker adjudication of cases, which is vital in environmental matters where delays can lead to irreversible damage.
5. **Public Participation:** The NGT encourages public participation in environmental matters. It allows concerned citizens, NGOs, and other stakeholders to file petitions and be part of the legal process, promoting transparency and accountability.
6. **Advisory Role**:The NGT can also play an advisory role by providing expert opinions and recommendations to government authorities and other bodies on environmental matters. This can help in the formulation of effective policies and regulations.
7. **Precautionary Principle:** The NGT often follows the precautionary principle, which means that in cases of scientific uncertainty, action should be taken to prevent environmental damage. This principle guides decisions to protect the environment even when all scientific evidence is not available.
8. **No Adverse Impact on Environment:** One of the principles guiding the NGT is the "polluter pays" principle, which means that those who pollute or cause environmental harm are responsible for the costs of remediation and compensation to the affected parties.
9. **Binding Decisions:** The NGT's orders and judgments are legally binding and enforceable. Failure to comply with its decisions can result in penalties and other legal consequences.
10. **Diverse Range of Cases:** The NGT deals with a wide range of cases, from industrial pollution to wildlife protection. Some notable cases have involved issues like the cleaning of the Ganges River, air pollution in major cities, and forest conservation.

11. **Efficiency:** The NGT follows a simplified procedure to ensure that cases are disposed of quickly. It has the power to impose fines and penalties on parties responsible for environmental damage, which acts as a deterrent.
12. **Environmental Education:** The NGT promotes environmental awareness and education. It has taken initiatives to create public awareness about the environment and the importance of conservation.
13. **International Agreements:** The NGT considers international agreements and conventions on environmental matters while delivering judgments. This helps in aligning India's environmental policies with global standards.
14. **Strengthening Environmental Laws:** Through its decisions and recommendations, the NGT has played a significant role in strengthening environmental laws and regulations in India. It has often called for stricter enforcement of existing laws and the formulation of new ones.
15. **Challenges and Criticisms**: The NGT has faced challenges in terms of resource constraints, delays in appointments, and a high volume of cases. Some critics argue that its decisions are not always effectively implemented on the ground.

NGT dealing with:

1. Cases related to air and water pollution, including industrial pollution and waste disposal.
2. Cases concerning deforestation, illegal mining, and encroachment on forest lands.
3. Cases related to environmental impact assessments and clearances for infrastructure projects.
4. Cases involving noise pollution, including noise from construction activities or industrial units.
5. Cases related to the conservation of rivers, lakes, wetlands, and other ecologically sensitive areas.

The NGT has been instrumental in addressing a wide range of environmental issues and ensuring the protection and conservation of the environment in India. Its establishment has provided a dedicated forum for expeditious resolution of environmental disputes and has played a vital role in promoting environmental justice and sustainability.

Guideline of national green tribunal act 2010

The National Green Tribunal (NGT) Act of 2010 provides guidelines and procedures for the functioning of the NGT and the resolution of environmental disputes. Some key guidelines outlined in the NGT Act:

The Act establishes the NGT as a specialized environmental tribunal with multiple benches across the country. It provides details on the composition, qualifications, and appointment of members of the NGT, including both judicial and expert members.

The NGT Act specifies the jurisdiction of the tribunal, which includes matters related to the enforcement of environmental laws, the prevention and control of environmental pollution, and the conservation and management of natural resources. It outlines the types of cases that can be filed before the NGT and the scope of its authority.

The Act sets out the procedure for filing cases before the NGT. It outlines who can file a case, the format and content of the application, and the documents and fees required for filing. It also includes provisions for online filing of cases to ensure accessibility and efficiency.

The NGT Act defines the powers and functions of the NGT. It empowers the tribunal to hear and decide cases, issue orders, grant interim relief, award compensation, and enforce its decisions. The Act provides guidelines on how the NGT should conduct proceedings, including the power to summon witnesses, examine evidence, and pass orders.

The Act specifies the appellate authority for challenging the decisions of the NGT. It allows parties aggrieved by the NGT's order to file appeals before the Supreme Court of India. The Act provides guidelines on the process, time limits, and procedures for filing appeals.

The NGT Act empowers the NGT to award compensation for environmental damage or harm caused by activities in violation of environmental laws. It provides guidelines on determining the quantum of compensation and the factors to be considered in such cases.

The Act allows the NGT to appoint expert committees or committees of assessors to assist in technical matters or to provide expert opinions. These committees play a crucial role in providing scientific and technical inputs to support the decision-making process of the NGT.

The NGT Act provides guidelines on the execution and enforcement of orders issued by the NGT. It outlines the powers and procedures for enforcing the tribunal's orders, including the recovery of compensation and the penalty for non-compliance. It's important to note that the

NGT has also issued various rules and procedures, known as the National Green Tribunal Rules, 2011, which provide more detailed guidelines on the functioning and procedures of the NGT.

12.8. Summary

Air pollution is a significant environmental issue that poses risks to human health and the environment. Governments and regulatory bodies around the world have enacted various laws and regulations to prevent and control air pollution. While specific legislation may vary between countries, there are common approaches and measures used to address this problem. Many countries have established comprehensive air pollution acts or laws that provide a legal framework for addressing air pollution. These acts typically define air pollutants, set air quality standards, establish regulatory agencies, and outline the responsibilities of industries and individuals in controlling air pollution. Air pollution acts often include regulations that set emission standards for different sources of pollution, such as industries, power plants, vehicles, and domestic activities. These standards define the maximum permissible levels of pollutants that can be emitted, helping to reduce pollution levels and protect air quality. Air pollution acts often require the establishment of monitoring systems to measure and assess air quality. These systems involve the installation of monitoring stations to collect data on pollutant levels. The collected information helps in identifying pollution hotspots, evaluating compliance with emission standards, and informing policy decisions. Air pollution acts may include provisions for implementing control measures to reduce pollution levels. These measures can include the use of pollution control technologies, such as filters and scrubbers, in industrial processes. Additionally, regulations on vehicle emissions, fuel quality, and traffic management are implemented to curb pollution from transportation sources. Air pollution acts often require industries and other pollution sources to obtain permits or authorizations to operate. These permits outline specific pollution control requirements and may include periodic inspections to ensure compliance. Non-compliance with emission standards may result in penalties or sanctions. ir pollution acts recognize the importance of public awareness and involvement in pollution prevention. They often include provisions for public education campaigns, dissemination of information on air quality, and mechanisms for public participation in decision-making processes. Air pollution is a transboundary issue, and many countries engage in international cooperation to address it. Bilateral and multilateral agreements, such as the Paris

Agreement on climate change, facilitate collaboration in reducing greenhouse gas emissions and mitigating the impact of air pollution on a global scale. The National Green Tribunal in India is a vital institution for addressing environmental concerns and disputes. Its specialized focus on environmental matters, expert members, and the ability to provide efficient and effective remedies make it an essential component of India's environmental governance framework. While there are challenges and criticisms, the NGT's role in environmental protection and conservation cannot be understated. It continues to evolve and adapt to the changing environmental landscape in India, contributing to a more sustainable and ecologically responsible future.

12.9. Terminal question

Q.1: What are environmental acts? Discus the act related to prevention and control of environmental pollution.

Answer:---

Q.2: What are air acts? Discuss the air (prevention & control of pollution) act 1981.

Answer:---

Q.3: Write the air act amended by amendment 1987 briefly.

Answer:---

Q.4: What do you understand about motor act in India, discuss the motor vehicle act, 1988.

Answer:---

Q.5: Write the environment (protection) act 1986, and rules 1986.

Answer:---

Q.6: Discuss the national green tribunal act 2010 its needs and applications.

Answer:---

12.10. Further suggested Readings

13. Environmental Science, Subhas Chandra Santra, new central book agency, 3rd Edition, 2011.

14. A text Book of Environment Studies, Asthana, D. K. and Asthana, M. 2006, S. Chand & Co.

15. Environmental Chemistry, A.K. De, New Age Publisher International Pvt Ltd.

16. Textbook of Environmental Chemistry and Pollution Control, S.S.Dara and D.D. Mishra, S Chand & Co Ltd.

17. Environmental law by R.D.Vijayshekar, Judicial handbook on Environmental Law, Dinah Shelton and Alexandre Kiss.