Environmental Pollution and Control in Chemical Process Industries

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ENVIRONMENTAL POLLUTION AND CONTROL IN CHEMICAL PROCESS INDUSTRIES

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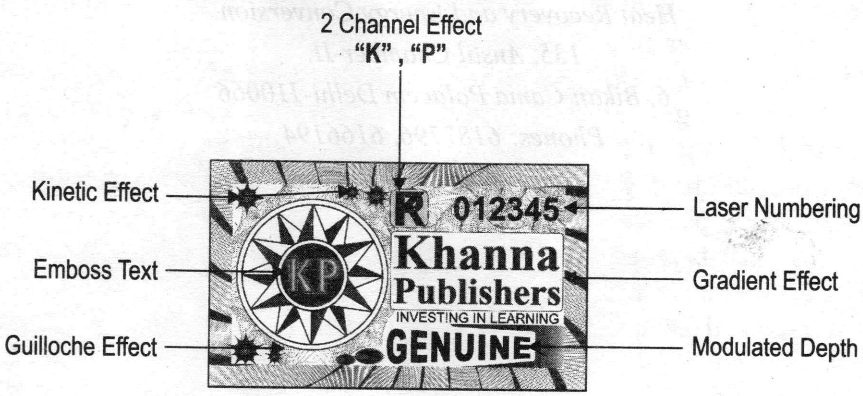

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Preface

Environmental pollution is a major hazard facing the world today and there is an increasing awareness of the fact that a clean environment is necessary for smooth living and the better health of human beings. Industrial projects have a profound influence on society and the environment not only in terms of benefits but also in risks and hazards. Industrial pollution affects factors which may cause illness, discomfort or lack of well-being among workers and the community as a whole. Industrial projects also bring about the concomitant ills of environmental pollution, depletion of resources, threats to human health, dwindling of forests and aesthetic nuisance. The adverse impact on the environment is largely due to indiscriminate and unregulated exploitation of both renewable and unrenewable resources and the use and abuse of the environment as a sink for dumping the waste products of development activities.

The ecological equilibrium of the earth is particularly endangered by the chemical process industries as the power plants continue to spew gaseous pollutants, chemical toxicants, heated effluents, fly-ash and other pollutants, posing grave pollution hazards. Recognising the need for a specialised book on this aspect, this text-book-cum-reference book has been written to serve as a comprehensive up-to-date source of information for undergraduate and postgraduate students.

Various treatment methods and preventive aspects of pollution are first discussed in a broad overview of general steps required and followed by a look at specific problems in chemical process industries which release emissions, wastewater, solid residue and effluents leading to degradation of the environment. The emphasis is on the imperative need for proper treatment systems to control pollution. Chapter 1 explains the meaning of industrial ecology and its interaction with environmental chemistry. Industrial pollution and the environmental impact of chemical intervention is the focus of Chapter 2 while Chapters 3 and 4 are devoted to air and water pollution. Air pollution has become a global reality and has caught the attention of society due to its rapid increase in industrial and urban areas. Since air is an everchanging and dynamic mixture of gases, particulates and micro-organisms, air monitoring strategy must be comprehensive, continuous and carefully planned. Keeping this in mind, Chapter 3 describes how monitoring of ambient air is done so that pollution control measures are effective. In Chapter 4, the latest technologies and methods for wastewater management in textile, paper and pulp and other mills are discussed including removal of phenol from wastewater by absorption techniques and by membrane technology.

Solid waste management is of growing importance, particularly in urban areas, and Chapter 5 deals with the sources and composition of solid wastes and the methods of waste disposal such as sanitary landfill, incineration, dumping, chemical processing and compaction. Modern life has given rise to a new form of pollution, noise pollution, a threat to the quality of our atmosphere and a health hazard in cities towns and factories as the ears are constantly assaulted by jarring high frequency range noise. This is the topic of Chapter 6 which also discusses various instruments used to measure noise at different levels and frequencies. The increase in industrial chemical activity has resulted potential for major industrial disasters, prompting safety analysts and scientists to take a closer look at the Chapter 7 which highlights the radiation pollution. Nuclear science which has produced a host of beneficial purposes, has led to the piling up of nuclear arsenals capable of wiping out the entire humanity in a few seconds time. Several nuclear accidents have created apprehension in the minds of millions of people about the hazardous radiation effects. The hazards are many, especially the risk of cancer chemical accident phenomena. Chapter 8 is thus devoted to safety and hazard analysis and management which is fast developing into a frontier discipline requiring high level knowledge of process technology and allied engineering sciences Chapter 9 deals with the related subject of environmental impact assessment which is the systematic identification and evaluation of the potential impacts of proposed projects, plans, programmes etc. on various components of the environment.

The chemical process industry has attracted a great deal of opprobrium on account of its poor record in the management of liquid and solid wastes. The quality and quantity of raw effluents vary not only from industry to industry but for the same type of industry. For example, it is no surprise that effluents from the cotton textile industry differ from those of synthetic textiles but it is suprising that effluents from one nylon textile factory may not be the same in quantity and quality as another nylon factory. In the light of this quality and quantity fluctuation, the design of an effluents treatment plant (ETP) has to be tailored to suit a particular industry as discussed in Chapter 10. Environmental audit or the process of detecting waste of resources and environmental damage that can be avoided in any productive activity is dealt in Chapter 11, illustrated by an interesting case study of NOCIL. Chapter 12 describes the principles, instruments and applications of instrumental techniques used for analysis of environmental samples essential for pollution control measures. The need for the enactment of legislation on environmental protection has become urgent in view of increasing pollution and Chapter 13 introduces, explains and critically appraises the pollution control laws in existence. Chapter 14 discusses the socio-political aspects of industrial pollution and strategies for preserving environmental quality in developing countries.

Focusing on the sugar industry, Chapter 15 deals with its effluents and wastes, sources of wastewater such as mill house and boiler blowdown, the intensive treatment of distillery wastewater which has become imperative because of strict water quality legislation and decrease in land availability and physico-chemical, biological and anaerobic treatment methods of waste. Chapter 16 elaborates on pesticides in the environment, including wastewater generation, treatment facilities and waste minimisation in pesticides while Chapter 17 discusses pollution control in the fertiliser industry following the three-pronged approach of pollution abatement at source, recycle, reuse and treatment of effluents. Drugs and pharmaceutical industries generate

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Section - I General Consideration

1

Industrial Ecology and Environmental Chemistry

1.0 Introduction

The two components of nature, organisms and their environment are not only much complex and dynamic but also interdependent, mutually reactive and interrelated. Ecology, relatively a new science, deals with the various principles which govern such relationships between organisms and their environment.

The term 'ecology' was coined by combining two Greek words, *oikos* (meaning 'house' or 'dwelling place') and *logos* (meaning 'the study of') to denote such relationships between the organisms and their environment. Thus literally, ecology is the study of organisms 'at home'. Ecology is the science of all the relations of all organisms to all their environment.

The recent development in study of ecology has been the recognition of the fact that the biotic (living) and abiotic (non-living) components of nature are not only interrelated but both these components function in an orderly manner as a definite system, thus structure and function should be studied together for fuller understanding of this vast nature. Biotic factors are the other organisms encountered, whether of the same or different species. Abiotic factors are the physical and chemical conditions such as temperature, moisture, respiratory gases, and substrate.

Industrial ecology (IE) is a new ensemble concept in which the interactions between human activities and the environment are systematically analysed. As applied to industry, IE seeks to optimise the total industrial materials cycle from virgin material to finished product to ultimate disposal of wastes. Industrial impacts on the environment and the means by which industrial processes can be adjusted to lessen these impacts through waste minimisation and recycling are also discussed under this topic. Although some of its individual elements have been recognised for some years, as applied to manufacturing, this systems-oriented concept suggests that industrial design and manufacturing processes are not performed in isolation from their surroundings, but rather are influenced by them and, in turn, influence them.

In industrial ecology, economic systems are viewed not in isolation from their surrounding systems, but in concert with them. That is, it is the study of all interactions between industrial systems and the environment. As applied to industrial operations, it requires a systems view in which one seeks to optimise the total industrial materials cycle from virgin material to finished material to component to product to waste product and to ultimate disposal. Factors to be optimised include resources, energy and capital.

A different form of definition arises by analogy to biological ecology. Traditional biological ecology is defined as the scientific study of the interactions that determine the distribution and abundance of organisms.

1.1 Ecosystem

An ecosystem is the whole biotic community in a given area plus its abiotic environment. It is the basic functional unit in ecology as it includes both organisms (biotic communities) and their abiotic (non-living) environment. The organisms interact with their abiotic environment and influence each other. Both biotic communities and their abiotic environment are necessary for maintenance of life as we have it on earth. It therefore includes the physical and chemical nature of the sediments, water and gases as well as all the organisms.

Structure of Ecosystem (Components of Ecosystem). An ecosystem has two major components.

I. Abiotic (Non-living) Components. It includes -

(*i*) The amount of inorganic substances as P, S, C, N, H, etc., involved in material cycles. The amount of these inorganic substances, present at any given time in an ecosystem, is designated as the standing state or standing quality.

(*ii*) Amount and distribution of inorganic chemicals, such as chlorophylls, etc., and of organic materials, as proteins, carbohydrates, lipids, etc., present either in the biomes or in the environment, i.e., biochemical structures that link the biotic and abiotic components of the ecosystem.

(*iii*) The climate of the given region.

II. Biotic (Living) Components. This is indeed the trophic structure of any ecosystem, where living organisms are distinguished on the basis of their nutritional relationships. From this trophic (nutritional) standpoint, an ecosystem has the following components.

(*a*) Autotrophic component (Producers).

(*b*) Heterotrophic component (Animals and decomposers).

(*i*) Macroconsumers or phagotrophs (Herbivores and carnivores).

(*ii*) Microconsumers and saprotrophs or detrivores (Bacteria and fungi).

Autotrophic Components. In these components fixation of light energy, use of simple inorganic substances and build up of complex substances predominate. The component is constituted mainly by green plants, including photosynthetic bacteria. To some lesser extent, chemosynthetic microbes also contribute to the build up of organic matter. Members of the autotrophic component are known as producers.

Heterotrophic Components. In these components utilisation, rearrangement and decomposition of complex materials predominate. The organisms involved are known as consumers, as they consume the matter built up by the producers (autotrophs). The consumers are further categorised as follows.

(i) Macroconsumers. These are the consumers, which in an order as they occur in a food chain are, herbivores, carnivores (or omnivores). Herbivores are also known as primary consumers. Secondary and tertiary consumers, if present, are carnivores or omnivores. They all are phagotrophs which include chiefly animals that ingest other organic and particulate organic matter.

(ii) Microconsumers. These are popularly known as decomposers. They are saprotrophs (osmotrophs) and include chiefly bacteria, actinomycetes and fungi. They breakdown complex compounds of dead or living protoplasm, absorb some of the decomposition or breakdown products and release inorganic nutrients in environment, making them available again to autotrophs.

It should be noted that these ecosystems are not closed systems because there is always an interflow of matter and energy between adjacent ecosystems.

Ecosystem Ecology. Ecosystem ecology emphasises the movements of energy and nutrients (chemical elements) among the biotic and abiotic components of ecosystems. Because the ecosystem is the highest level of biological organisation, all ecological concepts can be set within its framework. The biotic components of any ecosystem are linked as *food chains*. Food chains are interlinked to form complex *food webs*. Food webs are the basic units of ecosystem ecology. Thus ecology begins with populations and culminates in ecosystems.

Fig. 1.1 shows the basic patterns of energy and nutrient transfers in a generalised ecosystem. The patterns of energy and nutrient movements differ significantly in their relationships with the abiotic environment and with the ecosystem boundary. Energy flows through ecosystems, being acquired from outside as light energy from the sun and being intimately lost from the ecosystem as heat dissipated by the respiration of all community members. Nutrients are cycled within ecosystems to a much greater extent.

Also, there are involved energetics of ecosystem, as energy is the driving force of this system. The radiant energy is trapped by the autotrophic organisms (producers) and is transferred as organic molecules to the heterotrophic organisms (consumers). This energy flow is uni-directional or non-cyclic.

The chemical components of the ecosystem move in defined cycles—*biogeochemical cycles*. Within the ecosphere, biological systems frequently regulate the rate of movement of cycling of the chemicals. Role of water as the universal solvent for biological systems is very relevant here.

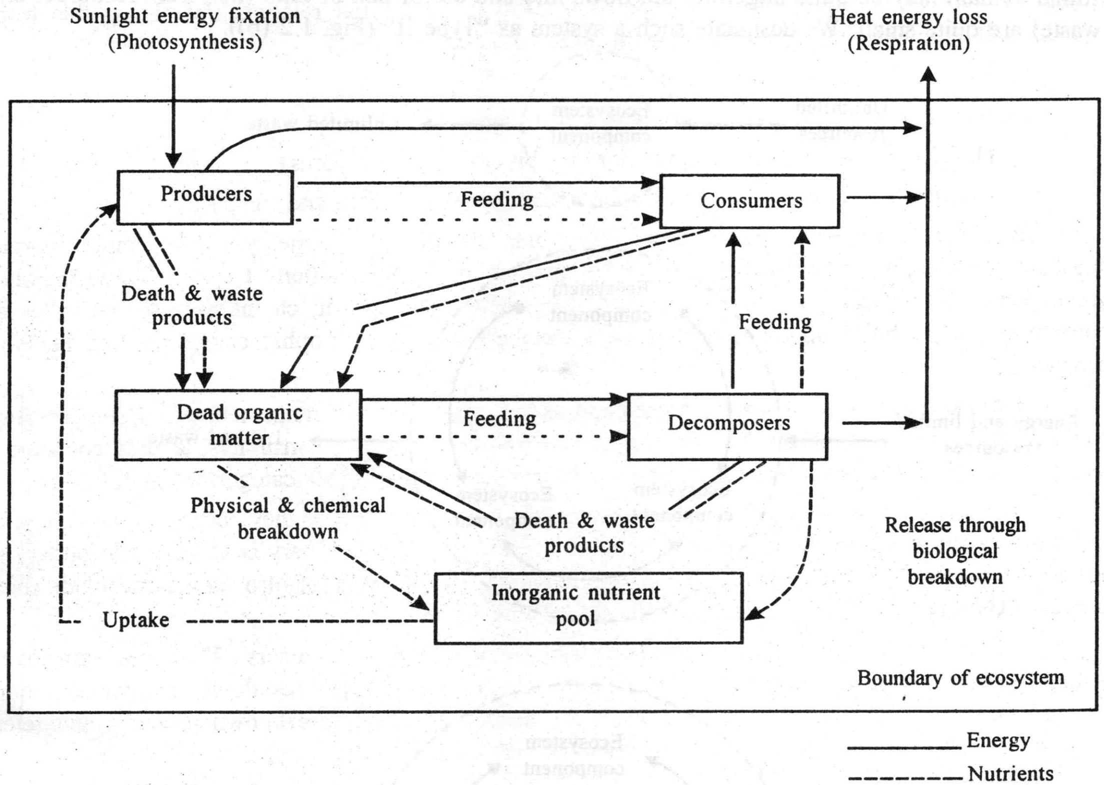

Fig. 1.1 Patterns of energy and nutrient exchange in a hypothetical ecosystem

In a biological ecosystem, some of the organisms use sunlight, water, and minerals to grow, while others consume the first, alive or dead, along with minerals and gases, and produce waste of their own. These wastes are in turn food for other organisms, some of which may convert the wastes into the minerals used by the primary producers, and some of which consume each other in a complex network of processes in which everything produced is used by some organism for its own metabolism. Similarly, in the industrial ecosystem, each process and network of processes must be viewed as a dependent and interrelated part of a larger whole. The analogy between the industrial ecosystem concept and the biological ecosystem is not perfect, but much could be gained if the industrial system were to mimic the best features of the biological analog.

It is instructive to think of the materials cycles involved with the earliest of Earth's life forms. At that time, the potentially usable resources were so large and the amount of life so small, that the existence of life forms had essentially no impact on available resources. This individual component process can be described as *linear*, i.e., the flow of material from one stage to the next is independent of all other flows. This pattern is designated "Type I" ecology; schematically, it takes the form of Fig. 1.2(a).

An aspect of biological ecology that is implied in its definition, but not stated, is that the totality of the ecosystem is sustainable over the long term, although individual components of the system may undergo transitory periods of expansion or decay as a consequence of proximal conditions. In the larger picture represented by an ecosystem in which proximal resources are limited, the resulting life forms are strongly interlinked. This evolution under the pressure of external constraints has produced in nature the efficiently operating system with which we are familiar. In this system, the flows of material within the proximal domain may be quite large, but the flows into and out of that domain (i.e., from resources and to waste) are quite small. We designate such a system as "Type II" (Fig. 1.2 (b)).

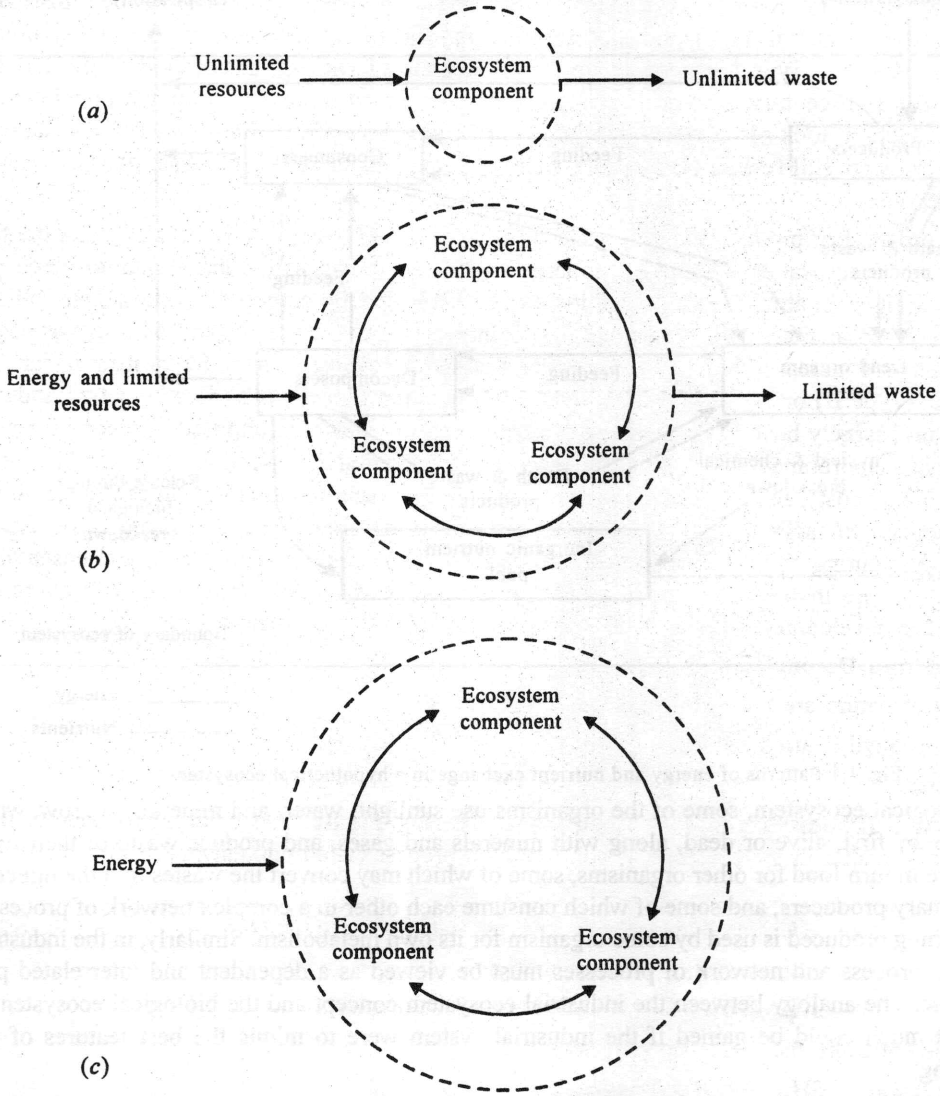

Fig. 1.2 (*a*) Linear materials flows in "Type I" ecology (*b*) Quasicyclic materials flows in "Type II" ecology (*c*) Cyclic materials flows in "Type III" ecology

A Type II system is much more efficient than a Type I system, but it clearly is not sustainable over the very long term, because the flows are all in one direction, i.e., the system is "running down." To be ultimately sustainable, biological ecosystems have evolved to be almost completely cyclical when sufficiently long time scales are considered. "Resources" and "waste" are undefined, since waste to one component of the system represents resources to another. This Type III system, in which complete cyclicity has been achieved, is pictured in Fig. 1.2 (c). Note that the exception to the cyclicity of the overall system is that energy (in the form of solar radiation) is available as an external resource. It is also important to recognise that the cycles within the system tend to function on widely differing temporal and spatial scales, a behaviour that greatly complicates analysis and understanding.

The ideal anthropogenic use of the materials and resources available for industrial processes (broadly defined to include agriculture, the urban infrastructure, etc.) would be one that is similar to the ensemble biological model. Many uses of materials have been and continue to be essentially dissipative, however. That is, the materials are degraded, dispersed, and lost to the economic system in the course of a single normal use. The Type I pattern above can be associated with the maturation of the Industrial Revolution of the 18th century, which, in concert with exponential increases in human population and agricultural production, took place essentially in a context of global plenty. Many present-day industrial processes and products still remain primarily dissipative. Examples include lubricants, paints, pesticides, and automobile tyres.

On the broadest of product and time scales, many indicators have begun to suggest that the flows in the ensemble of industrial ecosystems are so large or resistant to cyclisation that limitations are setting in— the rapid changes in atmospheric ozone, increases in atmospheric carbon dioxide, and the filling of available waste disposal sites being examples. Accordingly, industrial systems (and other anthropogenic systems) are and will increasingly be under selective pressure to evolve so as to move from linear (Type I) to semicyclic (Type II) or cyclic (Type III) modes of operation. For the past decade or two, industrial organisations have largely been in the position of responding to legislation imposed as a consequence of real or perceived environmental crises. Such a mode of operation is essentially unplanned, imposes significant economic costs, and may solve one problem only by exacerbating others. In contrast, industrial ecology is intended to facilitate the evolution of manufacturing from Type I to Type II or Type III behaviour by explaining the interplay of processes and flows and by optimising the ensemble of considerations that are involved. A central goal of industrial ecology, in combination with appropriate activities in other development sectors, is to achieve sustainable development.

1.2 Production and Decomposition in Nature

The producers of nature are the following.

(*i*) Chlorophyll bearing plants.

(*ii*) Bacteria.

Production (Photosynthesis) by Chlorophyll Bearing Plants. The chlorophyll bearing plants manufacture food matter in the presence of sunlight by a process called photosynthesis. The equation is as follows.

$$CO_2 + 2H_2O \xrightarrow[\text{Light energy}]{} (CH_2O) + H_2O + O_2$$

(Carbohydrate)

in presence of enzyme system of chlorophyll

In this equation, there are two processes-

(*i*) *Oxidation* $2H_2O \longrightarrow 4H + O_2$

Water is oxidised with the release of oxygen gas.

(*ii*) *Reduction* $4H + CO_2 \longrightarrow (CH_2O) + H_2O$
(Carbohydrate)

Carbon dioxide is reduced to Carbohydrate with the release of water.

Bacterial Photosynthesis. In bacterial photosynthesis the equation is as follows.

$$O_2 + H_2S \longrightarrow (CH_2O) + H_2O$$

(An inorganic sulphur compound or an organic compound)

Here the reductant is not water, but an inorganic sulphur compound such as H_2S (as in green and purple sulphur bacteria) or an organic compound (as in purple and brown non-sulphur bacteria), hence oxygen is not released. The photosynthetic bacteria play only a minor role in the production of organic food and are mostly only aquatic (marine and fresh water). The green and purple sulphur bacteria are important in the sulphur cycle. They are anaerobes, i.e., function only in the absence of oxygen and occur in the boundary layer between oxidative and reduced zones in water or sediments where there is a light of low intensity. In tidal mudflats, these bacteria often form distinct pink or purple layers just under the upper green layers of mud algae. In healthy bodies of water such as a lake, these bacteria are not so important in food production as in stagnant bodies of water where they may account for about 25% of total photosynthesis. The non-sulphur bacteria are able to function both in the presence or absence of oxygen, they can also function both in the presence or absence of light as can many algae. Bacterial photosynthesis is helpful in polluted and eutrophicated waters and is being increasingly studied but there is no substitute for photosynthesis by chlorophyll bearing plants.

Role of Chemosynthetic Bacteria. The chemosynthetic bacteria are not capable of carrying on photosynthesis, and assimilate CO_2 by obtaining energy by the chemical oxidation of simple inorganic compounds, e.g., ammonia to nitrite, nitrite to nitrate, sulphide to sulphur and ferrous to ferric iron. The examples of this type of bacteria are the sulphur bacteria (Beggiatoa) found abundantly in sulphur springs, various nitrogen bacteria which play important roles in the nitrogen cycle. The hydrogen bacteria which also belong to this group is being studied for life-support system in spacecraft as on a weight basis they would be very efficient in removing CO_2 from the spacecraft atmosphere. These bacteria can grow in dark recesses of sediments and soil but most require oxygen, as such they play an important role in the recovery of mineral nutrients and rescue energy that would otherwise be lost for direct feeding by animals.

Heterotrophic Algae. Some species of algae are partly heterotrophic. For example, in northern Sweden (The Land of Midnight Sun), during summer phytoplankton in lakes are the producers but during winter (which may last for several months) they are the consumers when they consume the organic matter accumulated in water.

Respiration. The autotrophic metabolism is largely balanced by respiration (any energy yielding biotic oxidation). Respiration is a catabolic process and is of three types.

(*i*) *Aerobic respiration* is the respiration in the presence of oxygen gas. This gaseous oxygen is the hydrogen (electron) acceptor (oxidant). Aerobic respiration is the reverse of photosynthesis.

(*ii*) *Anaerobic respiration* is the respiration in the absence of oxygen. Here in place of oxygen, an inorganic compound, other than oxygen is the hydrogen acceptor (oxidant), e.g., saprophages, i.e., bacteria (methane bacteria which decomposes organic compounds with the production of methane gas) (Swamp gas which rises to the surface where it can be oxidised or if it catches fire, it may become an unidentified flying object), moulds, protozoa, etc. Anaerobic respiration also occurs within certain tissues of higher animals.

(*iii*) *Fermentation* is also anaerobic but here an organic compound is the electron acceptor (oxidant), e.g., yeasts which are abundant in soils where they play a key role in decomposition of plant residues. Yeasts are also of commercial importance to man.

Certain bacteria like methane bacteria are only capable of anaerobic respiration (obligate anaerobes) while others like Aerobacter are capable of both aerobic and anaerobic respiration (facultative anaerobes). In this case, the end products of the two reactions are different and the amount of energy released is much less under anaerobic conditions. The facultative anaerobes are the minority components of the community but are important in the ecosystem as they alone can respire in the dark oxygenless recesses of the system. By occupying this inhospitable habitat, they 'rescue' energy and materials for many aerobes of the ecosystem. The sewage disposal system is a heterotrophic ecosystem, and depends on the partnership of aerobic and anaerobic saprophages.

Decomposition

***(i)* Decomposition, a vital function**. Decomposition is a vital function because if it did not occur all the nutrients would be soon tied up in dead bodies and no new life would be produced.

***(ii)* How does decomposition occur in nature?** Decomposition is chiefly due to the action of heterotrophic micro-organisms or saprophages that act upon the dead bodies of plants and animals. This kind of decomposition is the result of the process by which bacteria and fungi obtain food for themselves. In the bacterial cells and fungal mycelia there are enzymes necessary to carry out specific chemical reactions. These enzymes are secreted into the dead matter, some of the decomposition products are absorbed into the organism as food and others remain in the environment (as minerals in soil, as gases in atmosphere) or are excreted from the cells. It should be noted that no single species of saprotroph can produce complete decomposition of a dead body. Many species of decomposers are present in the biosphere which by their gradual action, effect complete decomposition. The rates at which different parts of the bodies of plants and animals are broken down also differ, e.g., fats, sugars and proteins are decomposed readily but cellulose, lignin (wood), chitin, hair and bones are acted upon very slowly. The products which are more resistant finally form 'humus' which is a dark, often yellow brown amorphous or colloidal substance. The humus of different ecosystems is almost the same in physical properties or chemical structure. It is difficult to characterise humus chemically as it originates from a great variety of organic matter. In general humus or humid substances are condensation products of proteins and polysaccharides. It is not known whether the organisms which decompose humus are separate from those which decompose fresh organic matter.

***(iii)* Role of matter undergoing decomposition.** Humus, detritus and other organic matter undergoing decomposition play an important role in soil fertility. If present in a moderate quantity, they provide a texture which is favourable for plant growth as many of these organic form complexes with mineral nutrients which enhance uptake by plants. The decomposition products if present in certain concentrations (differing in case of different organisms) only are beneficial but in high concentrations, i.e., if they accumulate to the point of providing "too much of a good thing", they may be harmful. For example, soluble yellow organic acids (decomposition products of plant origin) are beneficial in low concentration in lakes but in high concentrations they absorb light and reduce photosynthesis.

***(iv)* Agents of decomposition.** The agents of decomposition are bacteria, yeasts and moulds which may work together or alternately Bacteria are more important in the breakdown of animal flesh while fungi play the major role in the breakdown of wood. For example, if cellulose is buried in the soil, fungi will first grow, the bacteria will appear when cellulose has broken up, nematodes and other soil invertebrates appear next and feed on these pieces and also on micro-consumers. The macro-consumers thus hasten the decomposition process.

1.3 Biochemical Cycles

The chemical elements including all the essential elements of protoplasm tend to circulate in the biosphere in characteristic paths from environment to organisms and back to environment. These more or less circular paths are known as biogeochemical cycles. The term *bio* refers to living organisms and *geo* to rocks, air, water and soil of the earth.

Types of Biochemical Cycles. The biogeochemical cycles are of two types.

(*i*) Gaseous cycles in which the reservoir is in the atmosphere or hydrosphere.

(*ii*) Sedimentary or mineral cycle in which the reservoir is in the lithosphere, i.e., earth's crust.

Both of these cycles involve biological and non-biological agents and both are more or less tied to another cycle—the water cycle. The following is an account of carbon, oxygen, hydrogen, nitrogen, phosphorus, calcium, sulphur and water cycles.

Carbon Cycle. Carbon is contained in all organic compounds: carbohydrates, proteins, fats and nucleic acids which make up a living being.

(*a*) Carbon dioxide goes into the living beings from atmosphere. The main source of carbon of living beings is the free atmospheric carbon dioxide (Fig.1.3). The producers are the first of the living organisms to entrap carbon from carbon dioxide. During photosynthesis, plants combine carbon dioxide with water to make carbohydrates as follows.

$$CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Radiant energy of sun}} C_6H_{12}O_6 + 6O_2 \text{ (Energy rich glucose)}$$

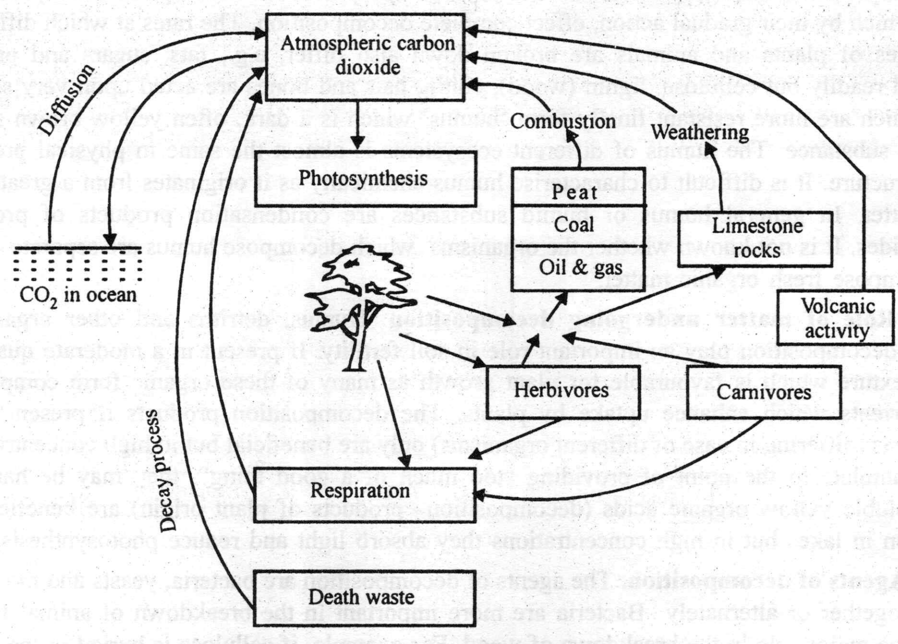

Fig. 1.3 Carbon cycle

About 4 to 9 $\times 10^{13}$ kg of carbon is fixed in photosynthesis annually. The simple carbohydrates synthesised by plants are converted into complex carbohydrates (polysaccharides) which are stored in plant tissues. Plants are eaten by herbivores who digest these and resynthesise these carbon compounds into their own types of carbon compounds. Carnivores feed upon herbivores, they digest the carbon compounds of herbivores and resynthesise them into their own.

(*b*) Carbon gets back into the atmosphere. Carbon is returned back to the atmosphere mainly by the following ways.

(*i*) By respiration.

(*ii*) The dead remains of plants and animals undergo decay process due to the activity of decomposers. This releases the locked up carbon dioxide into the atmosphere.

(*iii*) Part of the organic carbon gets burried in the earth's crust and gives rise to fossil fuel (peat, coal, oil and gas) in course of time. By burning of this fuel, carbon dioxide is returned to the atmosphere.

(*iv*) Part of the organic carbon gets burried in the earth's crust and gives rise to limestone rocks, by the weathering of these rocks, carbon dioxide is returned into the atmosphere.

(*v*) Hot springs and volcanic activity pours out about 100 million tonnes of carbon dioxide back into the atmosphere in a year.

(*c*) **Carbon dioxide dissolved in water.** Carbon dioxide dissolved in water of the oceans is the second important source of the gas. Carbon dioxide of atmosphere is in a dynamic equilibrium with that of oceans, so if its concentration in the atmosphere goes down, there is a movement of the gas from the oceans to the atmosphere and vice-versa.

Oxygen Cycle

(*a*) **Oxygen enters into the living beings.** The main source of oxygen are the green plants which give out oxygen during photosynthesis according to the equation :

$$6\ CO_2 + 6H_2O \xrightarrow[\text{Energy}]{\text{Sunlight}} C_6H_{12}O_6 + 6O_2$$

Oxygen which is thus released into the atmosphere, constitutes about 21% of air. From the atmosphere, oxygen enters into the living beings as a respiratory gas (Fig. 1.4). In course of respiration, oxygen combines with hydrogen to form water which becomes a part of the general water content of the living substance.

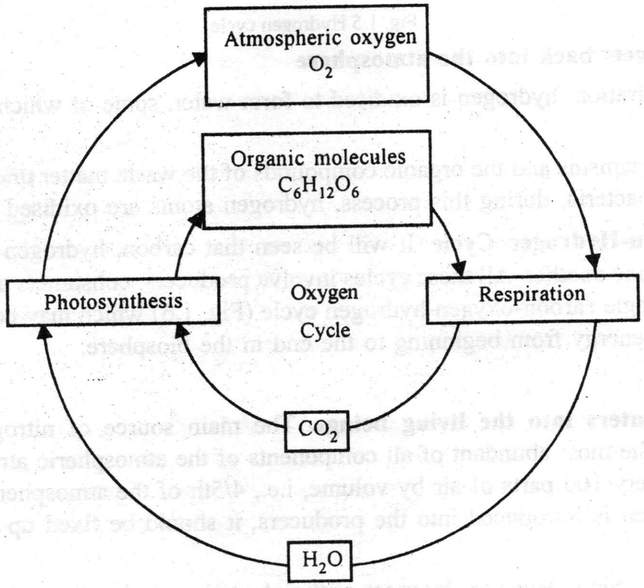

Fig. 1.4 Oxygen cycle

(*b*) **Oxygen gets back into the atmosphere.** Oxygen is returned back to the atmosphere, after death and decay of organisms, not as free oxygen, but as water or carbon dioxide.

Hydrogen Cycle

(a) Hydrogen enters into the living beings. The only source of hydrogen is the water molecule in the atmosphere (Fig. 1.5). Hydrogen enters into the living beings through photosynthesis during which water molecule is split up into oxygen and hydrogen. Hydrogen enters into the composition of glucose molecule and oxygen is released into the atmosphere. Through glucose, hydrogen moves into various organic components that are synthesised directly or indirectly from glucose and becomes part of the living matter.

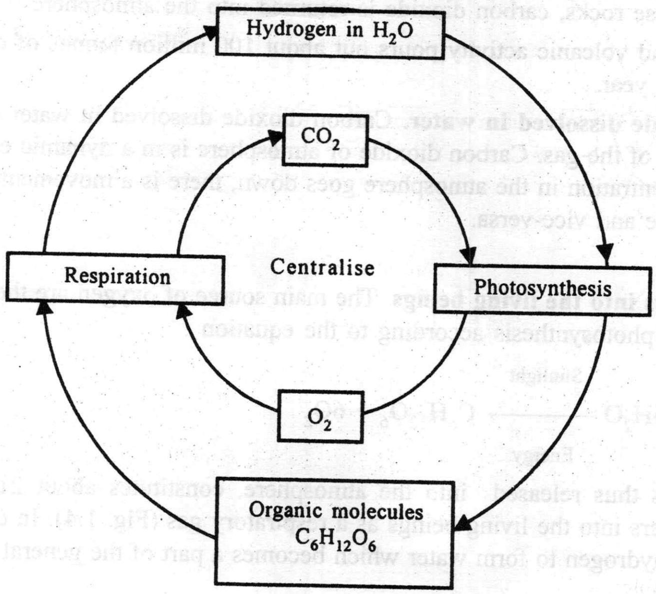

Fig. 1.5 Hydrogen cycle

(b) Hydrogen gets back into the atmosphere

(i) During respiration, hydrogen is oxidised to form water, some of which forms a part of the air which is breathed out.

(ii) The dead organisms and the organic compounds of the waste matter undergo decomposition by the activity of decay bacteria, during this process, hydrogen atoms are oxidised to form water again.

Carbon-Oxygen-Hydrogen Cycle. It will be seen that carbon, hydrogen and oxygen cycles are inseparably related to one another. All these cycles involve producers, consumers and decomposers, hence are combined into a single carbon-oxygen-hydrogen cycle (Fig. 1.6) which may be called as *energy cycle* as it involves flow of energy from beginning to the end in the biosphere.

Nitrogen Cycle

(a) Nitrogen enters into the living beings. The main source of nitrogen is the atmosphere (Fig.1.7). Nitrogen is the most abundant of all components of the atmospheric air. There being about 78 parts of nitrogen in every 100 parts of air by volume, i.e., 4/5th of the atmospheric air is pure nitrogen. Before this free nitrogen is introduced into the producers, it should be fixed up into an inorganic ion– the nitrate (NO_3).

As *Nitrates*, nitrogen is taken up by most of the plants in solution form. Some plants may absorb nitrites and use it to some degree though nitrogen is relatively toxic as nitrites. Some autotrophic and many heterotrophic marine bacteria are capable of utilising *ammonia* to synthesise their proteins. Some plants absorb nitrogen as organic nitrogen, (i.e., nitrogen in the protoplasm of organisms), e.g., many

Environmental Pollution and Control in Chemical Process Industries

Environmental pollution is a major hazard facing the world today and there is an increasing awareness of the fact that a clean environment is necessary for smooth living and for the better health of human beings. Industrial projects have a profound influence on society and the environment not only in terms of benefits but also in risks and hazards. Industrial pollution affects factors which may cause illness, discomfort or lack of well-being among workers and the community as a whole. Industrial projects also bring about the concomitant ills of environmental pollution, depletion of resources, threats to human health, dwindling of forests and aesthetic nuisance. The adverse impact on the environment is largely due to indiscriminate and unregulated exploitation of both renewable and unrenewable resources and the use and abuse of the environment as a sink for dumping waste products of development activities.

The ecological equilibrium of the earth is endangered by the chemical process industries, fly-ash and other pollutants, posing grave pollution hazards. Recognising the need for a specialised book on this aspect, this text-cum-reference book has been written to serve as a comprehensive up-to-date source of information for undergraduate and postgraduate students of engineering.

This book covers different types of pollution in chemical and allied industries, the extent and their nature, source of pollution, their adverse effects & their control and remedial measures. The text is supported by numerous examples, flowcharts and technical data which will enable the reader to grasp the information quickly and easily.

The text is further supplemented by latest techniques and methods of treatment of wastes and other polluting agents. Besides this separate chapter focuses on emerging topics viz. hazards management, environmental impact assessment, environmental audit and pollution control laws and acts. In the end, few case studies have been given to highlight the problem and effects of the various kinds of industrial pollution to society and environment at large.

Contents at a glance

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