Microbiology of Solid Waste, Sewage (Wastewater) and Industrial Wastes

Human activities create vast amounts of various solid and liquid **wastes**. The release of these materials into the environments causes serious health problems as they make undesirable changes in our land and water resources making them unfit for use. Proper treatment of such wastes is necessary, using microbial biodegradation/detoxification. In this chapter we would discuss some of the methods which make environmental use of microorganisms to maintain environmental quality and safe disposal of waste materials. The **chief wastes** of concern are : (i) solid wastes, (ii) liquid wastes, also called domestic wastewater or sewage and (iii) industrial wastes, such as pesticides, oil spills etc.

Solid Waste Disposal

Besides the inert part such as glass, metal and plastic, the solid wastes also contain degradable organic waste such as kitchen scraps, paper and other household and industrial garbage. Sewage sludge derived from treatment of liquid wastes, animal waste from cattle feed lots, and poultry and swine farms are also major sources of solid organic waste. In rural areas these may be recycled into land as fertilizer. However, in urban areas they pose an environmental problem.

Major cities generate two major types of solid wastes : (i) **municipal solid waste (MSW),** which includes the inert part such as glass, metal and plastic, as well as degradable organic waste such as food, animal and plant residues, kitchen scraps, paper and other household and industrial garbage, and (ii) **sewage sludge** or **biosolids** derived from treatment of liquid wastes, animal waste from cattle feed lots, and poultry and swine farms. Following microbiological methods have been developed to treat these wastes by way of using microbial biodegradation.

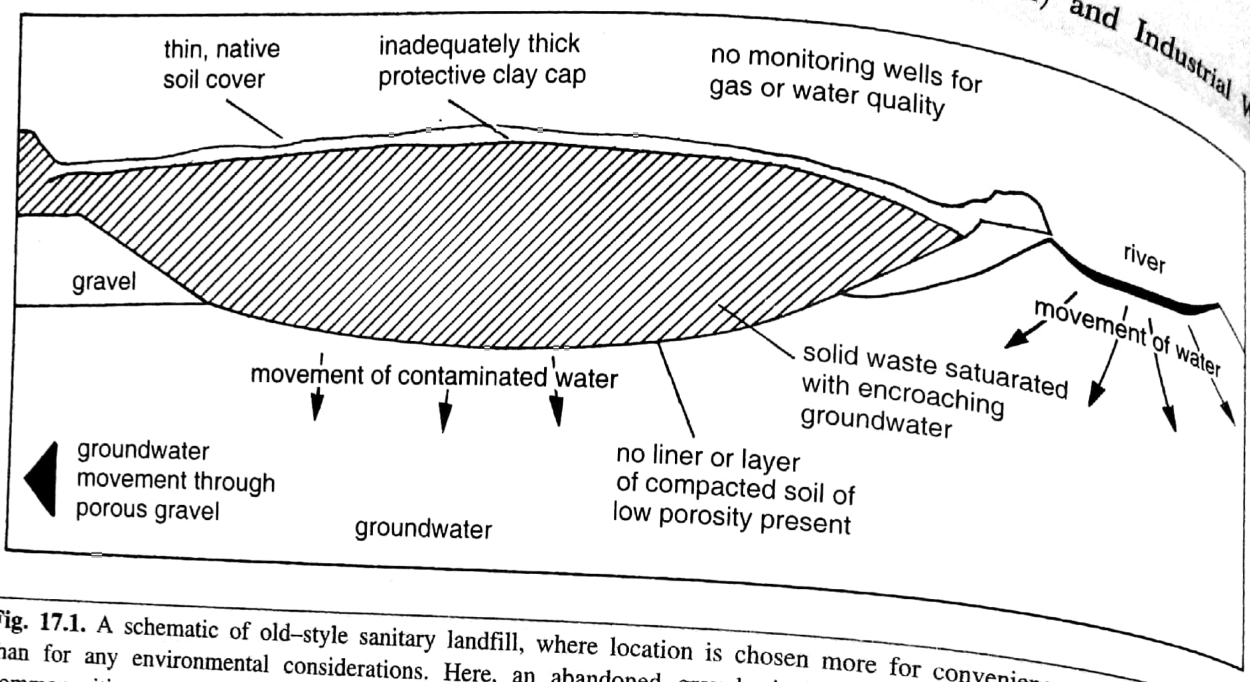

Fig. 17.1. A schematic of old–style sanitary landfill, where location is chosen more for convenience or budgetary concerns than for any environmental considerations. Here, an abandoned gravel pit located near a river exemplifies an all too common siting arrangement.

Sanitary Landfills

The material is placed in a landfill to allow it to decompose. Both, organic and inorganic solid wastes are deposited together in a low–lying land. To avoid foul odour and attraction of insects and rodents, each day's waste deposit is covered over with a layer of soil, creating a **sanitary landfill.** A developed landfill can be used for construction and recreation purpose. For 30–50 years, the organic matter undergoes slow, anaerobic microbial decomposition and the resulting products, CO_2, H_2O, CH_4, low mol. wt. alcohols, and acids diffuse in the surrounding air and water. Thus landfill settles down.

Various methods are used for making sanitary landfills. These are, (i) **area method** where a bulldozer spreads and compacts solid waste; cover material is hauled in and spread at the end of operation, (ii) **trench method,** in which the waste collection truck deposits its load in a trench where it is spread and compacted, and (iii) **ramp variation,** where solid wastes are spread and compacted on a slope.

Old–style sanitary landfills (Fig. 17.1) were constructured at locations chosen more for convenience or budgetry concerns than for any environmental considerations. These may be abandoned pits located near a river, mine etc. In such landfills conditions were favourable to pollution, particularly water pollution caused by the leachates pproduced by the infiltration of water through the water material. Besides contaminated water, such landfills release pollutants also into the air. Anaerobic microbial activities generate greenhouse gases, such as N_2O, CH_4 and CO_2.

A **modern-style** landfill (Fig. 17.2) is designed to meet exact standards for of all materials, including leachates containment and gases. It should have minimum impact on the environment, with special reference to groundwater protection. Geology and soil type, groundwater considerations as water table depth etc. are taken into account. Fresh garbage is covered daily with a layer of soil. The high temperatures (50°C) generated during the decomposition of buried or composted waste inactivates most of the enteric pathogens present in the waste.

Composting

Here the organic part of waste is biodegraded by composting. In this process, the waste is degraded by aerobic, mesophilic and thermophilic microbes. Inorganic fraction is separated either at source or by using magnetic separators. Organic fraction is ground up, mixed with sewage sludge and/or bulking agents (shredded newspaper wood chips) and then

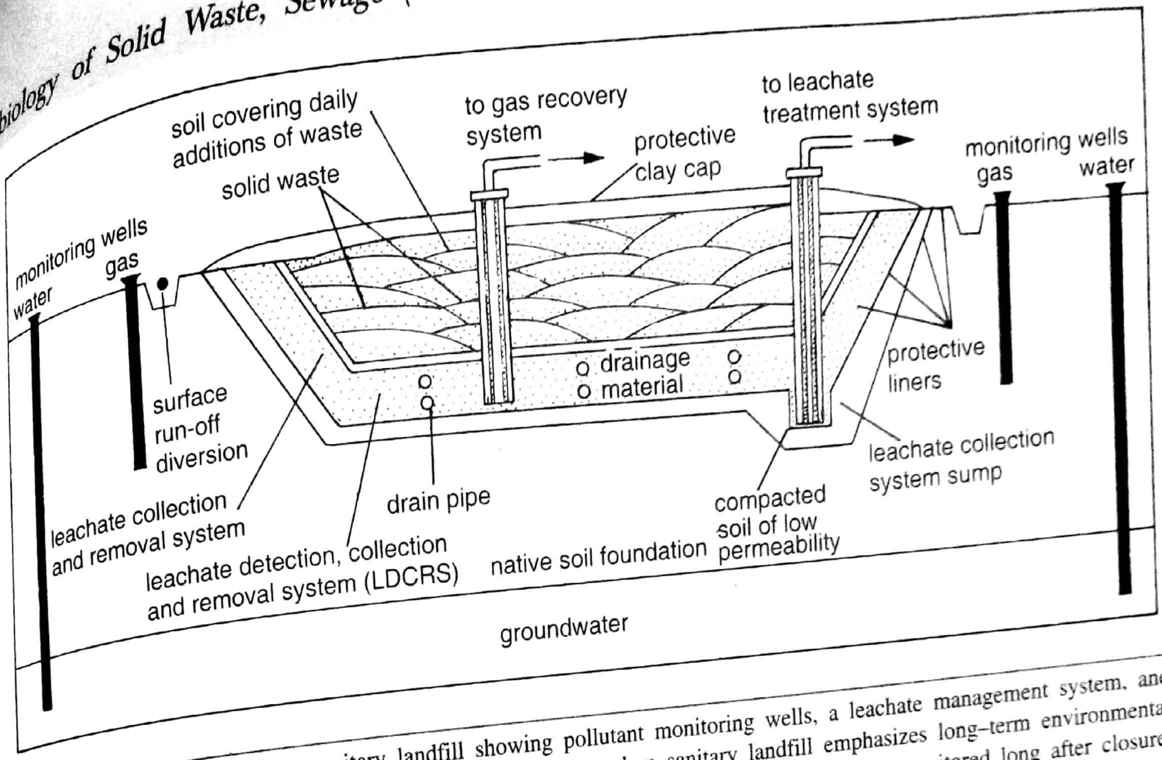

Fig. 17.2. Cross–section of a modern sanitary landfill showing pollutant monitoring wells, a leachate management system, and leachate barriers. In contrast to the old–style site (Fig. 17.1), the modern sanitary landfill emphasizes long–term environmental protection. In addition, whereas landfills were formerly abandoned when full, a modern landfill is monitored long after closure.

composted. This balances C : N balance. Microbial composting converts the waste into a stable, sanitary, humus–like product. The various composting methods are used. These include the following :

Window method

Solid waste is arranged in long rows and covered to allow decomposition. Material is turned over repeatedly.

Static pile or aerated pile method

Here composting rates be enhanced by forced aeration. Waste is arranged in piles and forced aeration is used to supply extra–O_2. Perforated pipes are buried inside the compost pile and the air is then pumped (Fig. 17.3)

In–vessel or mechanical or enclosed–reactor composting method

It is a continuous feed approach. It may incorporate the feature of window and/or static pile methods of composting. It uses a reactor that permits control of the environmental parameters. Reactor is like an industrial fermenter. Here composting is complete within 2–4 days. But this method is expensive.

At present, most of the operational facilities use static pile composting or window method. These two methods yield stable products, and are low in cost. In compost of domestic garbage and sludge, several microbial species that come from soil, water and human fecal matter are present. High moisture content of the compost favours the growth of bacteria than fungi. Mesophiles are the first to appear and as the temperature rises thermophiles begin to grow. Thermophiles that are dominant in compost include bacteria, like *Bacillus stearothermophilus*,

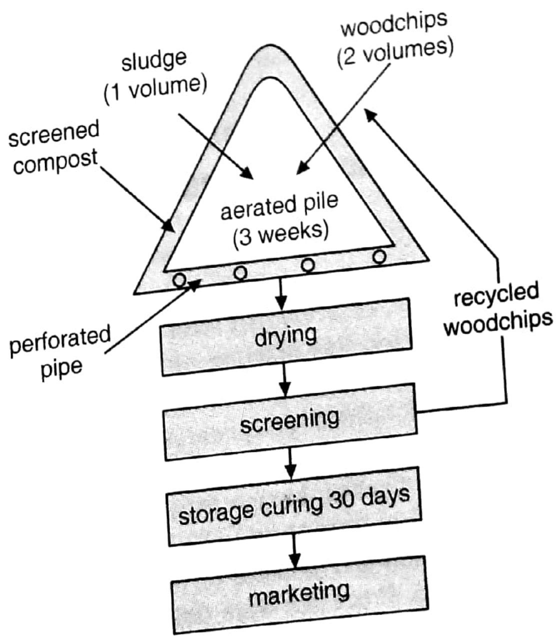

Fig. 17.3. An outline of static aerated pile composting method.

Table 17.1. Typical constituents of untreated domestic sewage.

Components	Concentration (mg/l) Low	Moderate	High
Solids (total)	350	720	1200
Dissolved (total)	250	500	850
Volatile	105	200	325
Suspended solids	100	220	350
Volatile	80	165	275
Setteable solids	5	10	20
BOD	110	220	400
Organic carbon (total)	80	160	290
COD	250	500	1000
Nitrogen (total as N)	20	40	85
Organic	8	15	35
Free NH_3	12	25	50
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	4	8	15
Organic	1	3	5
Inorganic	3	5	10

Thermomonospora spp. *Thermoactinomyces* spp. and *Clostridium thermocellum,* and fungi, such as *Geotrichum candidum, Aspergillus fumigatus, Mucor pusillus, Chetomium thermophile, Thermoascus auranticus* and *Torula thermophila.* The reactor is maintained at thermophilic temperatures. Maximum composting occurs at 50–60 °C, moisture should be 50–60% water content, the C: N ratio must not exceed 40 : 1, the lower nitrogen will not allow the growth of enough microbial biomass.

Sewage (Domestic Wastewater) Treatment

During ancient times human wastes were simply discharged into the nearest body of water, such as lake, stream, river, or ocean. In rural areas of many developing countries, this practice still continues. As the human population size grew, these water bodies became degraded, affecting aquatic wildlife due to depleting levels of oxygen. Moreover waterborne diseases began to threaten human lives also. Diseases like cholera became very common. This prompted the proper collection and disposal of domestic wastes of populated areas. Processes were developed to treat this waste before its disposal in natural water bodies. Sewage treatment is a relatively modern practice which virtually began at the turn of 20th century.

Components of Domestic Wastewater

Domestic wastewater or **sewage** is primarily a combination of human faecal matter, urine and graywater. Graywater results from washing, bathing, and meal preparation. Water from various industries and business establishments may also enter the system. Major organic and inorganic constituents of untreated domestic sewage are shown in Table 17.1

The amount of organic matter in domestic wastes determines the degree of biological treatment required. Three tests are used to asscess the amount of organic matter : total organic carbon (TOC), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). The major objective of domestic waste treatment is the reduction of BOD, which may be in soluble or solid state.

Pathogenic microorganisms are invariably present in domestic wastewater (Table 17.2). Their chief source appears to be the excreted matter from infected persons.

Table 17.2. Microorganisms typically reported from untreated domestic wastewater.

Microorganisms	Concentration (per ml)
Total coliform	10^5–10^6
Faecal coliform	10^4–10^5
Faecal streptococci	10^3–10^4
Enterococci	10^2–10^3
Shigella	Present
Salmonella	10^0–10^2
Clostridium perfringens	10^1–10^3
Giardia cysts	10^{-1}–10^2
Cryptosporidium cysts	10^{-1}–10^1
Helminth ova	10^{-2}–10^1
Enteric virus	10^1–10^2

(Modified from Metcaff and Eddy, 1991)

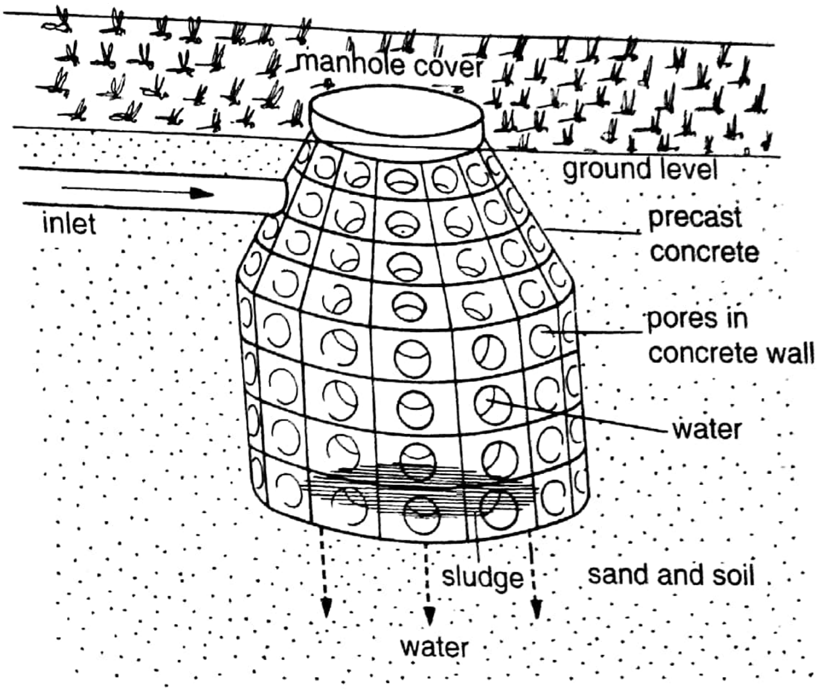

Fig. 17.4. Operation of the cesspool. Waste enters through the inlet pipe, and solid material falls to the bottom of the cesspool to form sludge. Water passes through the open bottom and through pores in the wall of the cesspool into the surrounding soil (sand).

Sewage is the used water supply containing domestic waste together with human excrement and wash water, and industrial waste, including acids, greases, oils, animal matter, vegetable matter and storm waters. The basic principle in sewage treatment is that water is separated from the waste while the solid organic matter is biodegraded by microorganisms to simple compounds like nitrates, sulphates, carbonates, carbon dioxide, methane etc. Knowledge of microbiology of sewage is central to maintenance of quality of environment. Sewage treatment is done both, at small as well as large scale.

Small Scale Sewage Treatment

This is managed on small scale as in individual homes, rural areas, and quite a few residents of town and small cities. They depend on cesspools, septic tanks (pit toilets or outhouses), or oxidation ponds for waste disposal.

Cesspools

In many homes, human waste is dumped into cesspools. A cesspool is an underground construction, consisting of concrete cylindrical rings with pores in the walls of ring (Fig. 17.4). Water passes out the bottom and through the pores into the surrounding sand, whereas the solid waste accumulates at the bottom. Anaerobic bacteria in the compacted sludge layer at the bottom of cesspool digest the organic matter. The breakdown products diffuse into the ground. After few years it may become necessary to pump out the sludge layer (if it becomes thicker) and to clean with strong acid. Chemicals that can digest the grease should also be added to avid blockage of the pores. Dried bacterial spores as those of *Bacillus subtilis* are available in stores. These may be added to accelerate the sludge digestion. Addition of yeasts at intervals is also useful.

Septic tanks

These are also used in some homes. A septic tank (Fig. 17.5) is an enclosed concrete box into which waste flows from the house. The organic matter accumulates at the bottom of tank whereas the water rises to the outlet pipe to flow to a distribution box. The box is then separated into pipes which empty into the surrounding area. The tank is to be pumped out regularly as there is to absorption of the digested organic matter into the earth. Small towns collect the sewage into large ponds called **oxidation lagoons.** The sewage is left in lagoon for a couple of months during which aerobic bacteria digest the organic matter in the water and anaerobic organisms breakdown the sedimented material.

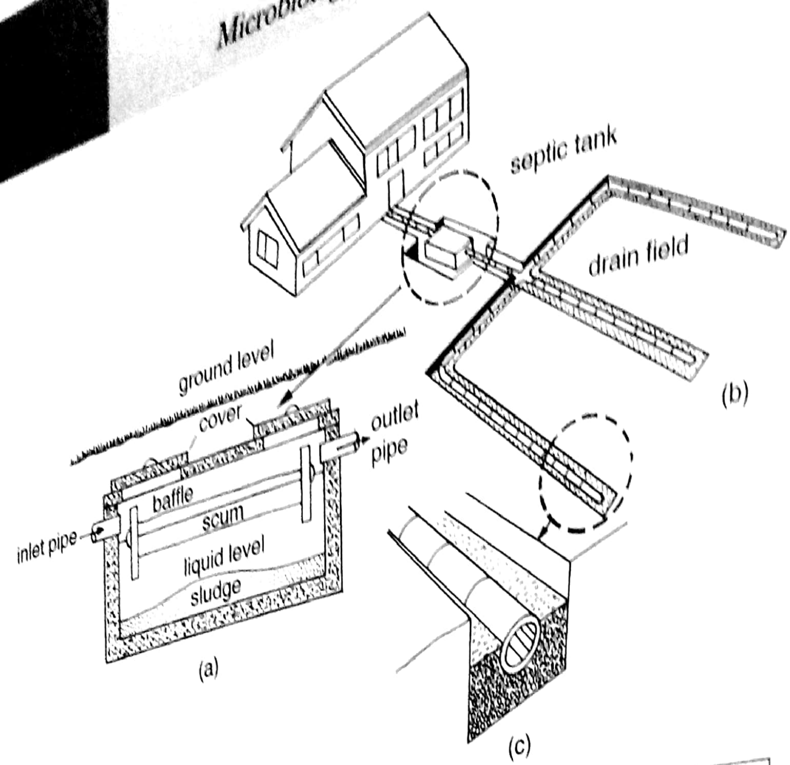

Fig. 17.5. Operation of the septic tank. Waste enters the enclosed septic tank (a) where solids fall to the bottom and accumulate as sludge, which in time decomposes. Relatively clear water passes through the outlet pipe and is distributed by a distribution box (b) into a buried field of clay pipes that open to the soil (c).

Oxidation ponds

Sewage lagoons are often referred to as **oxidation** or **stabilisation ponds** and are the oldest of the sewage treatment systems. Since they require a minimum of technology and are relatively of low cost, they are most common in developing countries. However, biodegradable organic matter and turbidity are not as effectively reduced as in modern activated sludge treatment systems. Oxidation ponds, used for simple, secondary treatment in rural areas are usually no more than a hectare in area and just a few meters deep. They are infact natural "stewpots" where wastewater is detained while organic matter is degraded. A period of 1-4 weeks or sometimes longer is required for complete decomposition of organic matter.

There are four categories of oxidation ponds, which are often used in series : aerobic ponds, aerated ponds, anaerobic ponds, facultative ponds and ... **Aerobic ponds** are naturally mixed, shallow to allow effective light penetration to stimulate algal growth which promotes subsequent O_2 generation. The wastewater is detaind generally for 3-5 days. **Anaerobic ponds** may be 1 to 10 m deep and require a relatively long (20-50 days) detention time and do not require much aeration. Often generating small amounts of slugde, they serve as a pretreatment step for high-BOD organic wastes. **Faculative ponds** are most common for sewage treatment. Sewage is treated by both aerobic and anaerobic processes. The ponds are 1 to 2.5 m deep and subdivided into three zones : an upper aerated zone, a middle facultative zone, and a lower anaerobic zone (Fig. 17.6). The

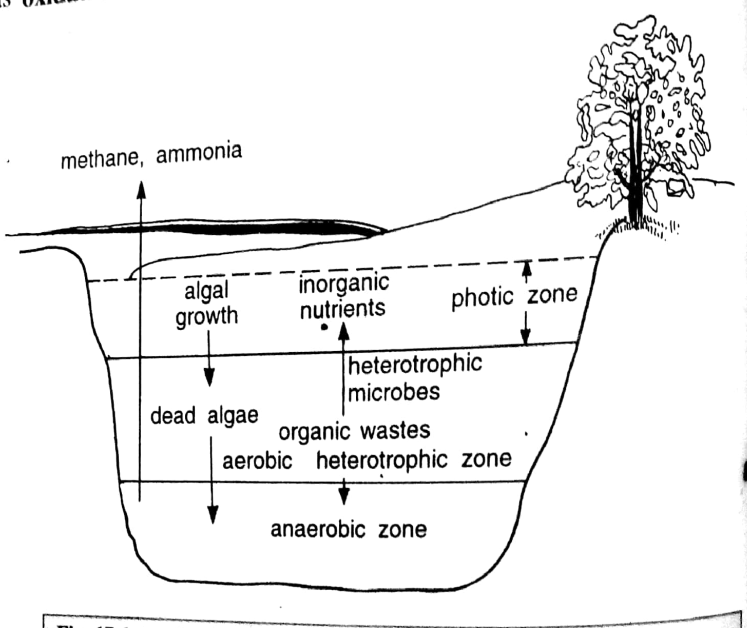

Fig. 17.6. A schematic of an oxidation pond showing the biological processes involved in this form of sewage treatment. The photic zone is highly productive. Dead algae fall into an aerobic heterotrophic zone where they are partially degraded, and then fall with dead bacteria into the anaerobic bottom layer of the pond.

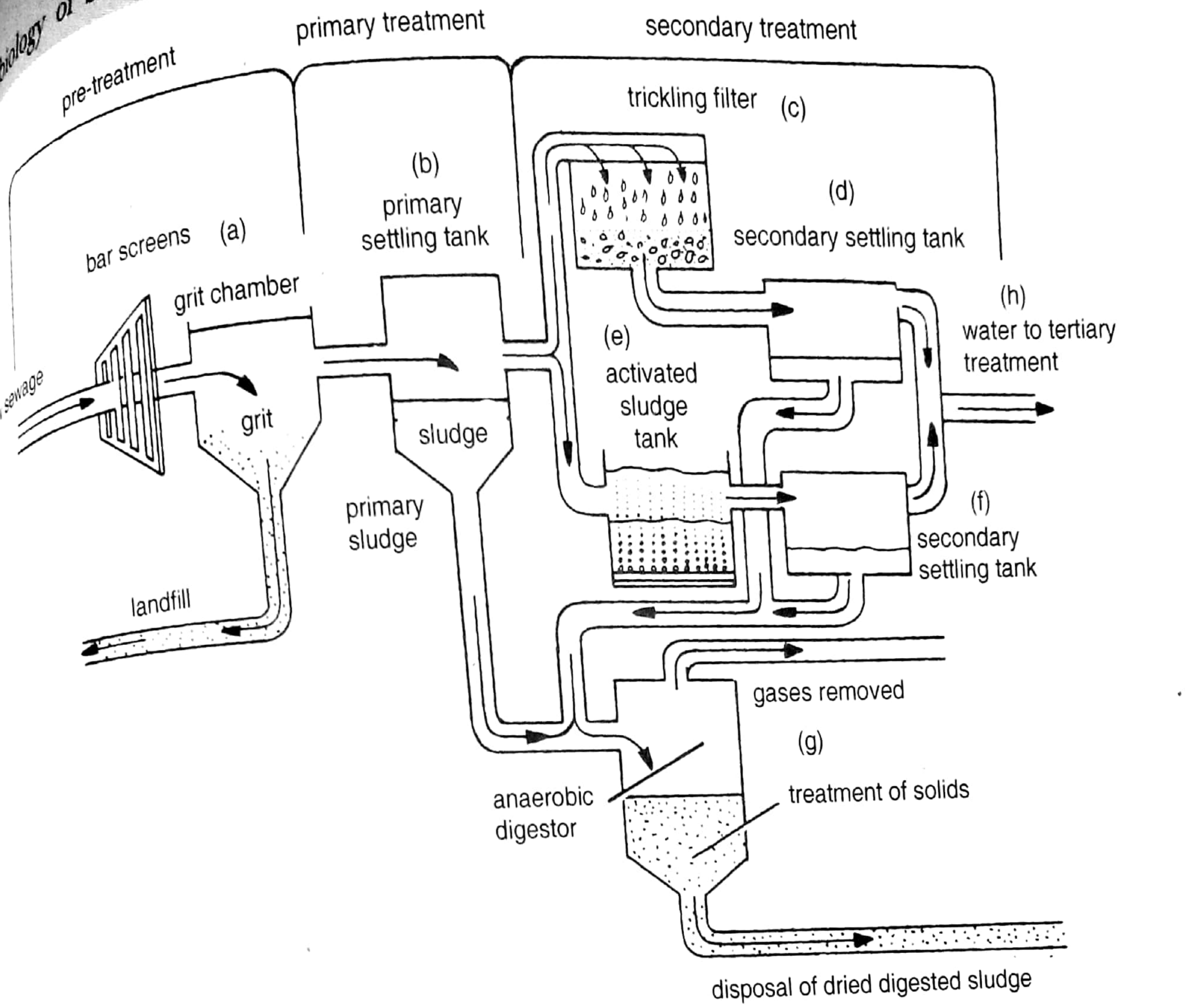

Fig. 17.7. A schematic view of modern large scale waste treatment facility. (a) sewage is initially pretreated with a bar screen to remove grit. (b) the sewage is then piped to a settling tank where organic waste passes out to a sludge tank. This is primary treatment. (c) in the liquid phase of secondary treatment, microorganisms digest the soluble organic matter as the water percolates through a filter. (d) the water is separated from the microorganisms and passes out, while the sedimented material flows to the sludge tank. (e) in the solid phase of secondary treatment, sludge is treated in an activated sludge tank with thorough aeration. (f) this is followed by separation and flow of sedimented material to the anaerobic sludge tank. (g) in the anaerobic sludge tank, sludge from three processes (b, d and f) is held for several weeks, during which anaerobic bacteria break down the sludge to usable end-products. (h) the water from the settling tanks may be further processed in tertiary treatment.

detention time varies between 5 and 30 days. **Aerated ponds** are mechanically aerated, may be 1-2 m. deep and have detention time of less than 10 days. Treatment depends on the aeration time, temperature as well as the composition of sewage.

Modern Large Scale Sewage Treatment

The primary objective of sewage treatment is the removal and degradation of organic matter under controlled conditions. Municipal plants are equipped for a mechanized sewage treatment that handles massive amounts of daily generated waste and garbage. A simplified view of such a waste treatment facility is shown in Fig. 17.7 The overall process can be divided into **three** steps : the primary, secondary and tertiary treatments (Fig. 17.8). These different treatments to sewage depend on the quality of the effluent deemed necessary to be achieved to permit the maintenance of acceptable water quality. **Primary treatments** rely on physical separation of large debris, followed by sedimentation; **secondary treatments** rely on microbial biodegradation to further reduce the concentration of organic compounds in the effluent; and the **tertiary treatment** is usually a physicochemical process that removes turbidity caused by the presence of nutrients (e.g. nitrogen), dissolved organic matter, metals or pathogens. Municipal treatment plants are not

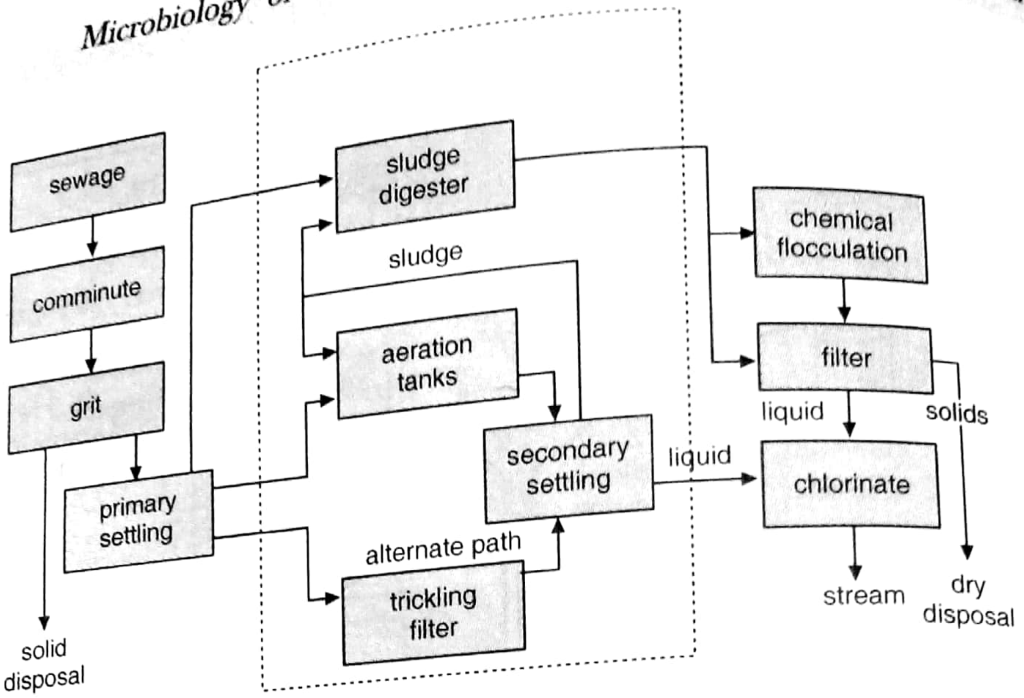

Fig. 17.8. Flow chart of the stages of sewage treatment. Primary treatment is mainly physical, secondary mainly biological, and the tertiary one mainly chemical.

capable of dealing with industrial wastes containing toxicants, such as heavy metals.

Primary treatment

This removes suspended solids in settling tanks or basins. Solids are drawn off. Raw sewage is piped into huge open tanks where it is screened to remove solid fraction. This solid material is then subjected to anaerobic digestion in landfill or composting. The liquid portion is then passed into sludge tanks for further treatment. Flocculating materials as aluminium or iron sulphate are also added to raw sewage to trap microbes and debris to the bottom as in the sedimentation process of water purification. These materials are added to sludge tanks also. In the settling tank suspended organic solids settle to the bottom as **sludge** or **biosolids**. The resulting sludge is referred to as **primary sludge**.

Secondary treatment (Microbial biodegradation)

To achieve an acceptable reduction in the BOD, secondary treatment by a variety of means is necessary (Table 17.3).

In this treatment a small portion of the dissolved organic matter is mineralised and the large portion is converted to removable solids. By now the original sewage BOD is reduced to 80-90 per cent. Secondary treatment relies on microbial activity which may be aerobic or anaerobic, and is conducted in large variety of devices. Since this step is a microbial process, accidental introduction of a toxic chemical is very dangerous. Various devices used in this treatment are as follows :

Oxidation ponds. Oxidation ponds or stabilization ponds and lagoons are used for simple

Table 17.3 **Efficiency of various types of sewage treatment.**

Treatment	BOD (% reduced)	Suspended solids (% reduced)	Bacteria (% reduced)
Sedimentation	30-75	40-95	40-75
Septic tank	25-65	40-75	40-75
Trickling filter	60-90	0-80	70-85
Activated sludge	70-96	70-97	95-99

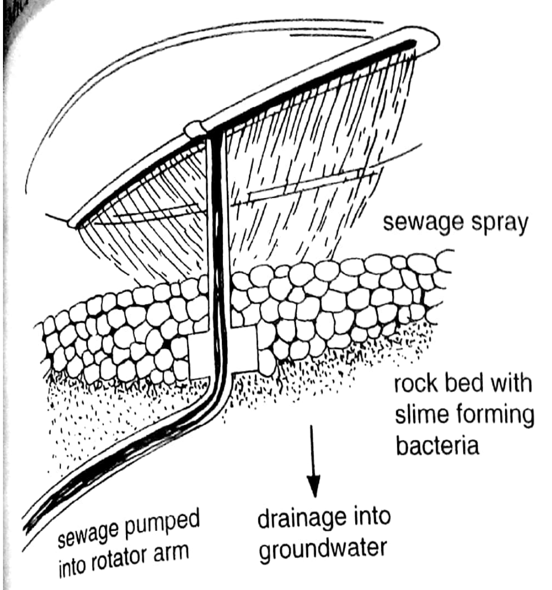

Fig. 17.9. A trickling filter, where the sewage is sprayed over rocks. The bacterial film on the rocks aerobically decomposes the dissolved organic matter. The drainage may go through the soil column to the groundwater or drain into a nearby river or ocean.

secondary treatment in rural areas or industrial units. Heterotrophic bacteria degrade sewage organic matter within ponds, producing cellular material and mineral products that support the growth of algae. Oxygen produced by algae compensate for the poor O_2 conditions created by heterotrophic bacteria. The pond should be shallow, 10 feet deep, to maximize the euphotic zone for algal growth. Bacterial and algal cells settle at the bottom of pond. Effluents containing oxidized products are periodically removed.

Trickling filter. This system is a simple and expensive film-flow type of aerobic sewage treatment device (Fig. 17.9). Sewage is distributed by a revolving sprinkler suspended over a bed of porous material. The sewage slowly percolates through this porous bed and the effluent collected at the bottom. The porous material of the filter bed becomes coated with a dense, slimy bacterial growth, mainly composed of *Zooglea ramigera* and similar slime-forming bacteria. This slimy matrix thus generated harbors a heterogeneous microbial community, including bacteria, fungi, protozoa, nematodes and rotifers. The most frequent bacteria are *Beggiatoa alba, Sphaerotilus natans, Achromobacter* spp, *Flavobacterium* spp, *Pseudomonas* spp and *Zooglea* spp. This community absorbs and mineralizes dissolved organic nutrients in the sewage reducing the BOD of the effluent. Porous bed allows aeration. Sewage may be passed through two or more trickling filters or recirculated through the same filter.

Biodisc system. The **biodisc system** or **rotating biological contactor** is a more advanced type of aerobic film-flow treatment system. Here, closely spaced discs, usually made of plastic are rotated in a trough containing the sewage effluent. The discs are partially submerged and become coated with a microbial slime similar to that developing in trickling filters. Continuous rotation of the discs keeps the slime well aerated and in contact with the sewage. Microbial growth on the disc surfaces is sloughed off gradually and removed by subsequent settling. When the film becomes so thick that O_2 and nutrients fail to reach the inner portion of film, the innermost microbes die, causing detachment of the film. The system is used in communities for treatment of domestic and industrial sewage effluents.

Conventional activated sludge. This process is also known as **aeration-tank digestion**. It is very widely used aerobic suspension type of liquid waste treatment system. After primary settling, the sewage is introduced into an aeration tank and mixed with a bacteria-rich slurry known as **activated sludge**. Air injection and/or mechanical stirring provides aeration. The rapid development of microbes is also stimulated by reintroduction of most of the settled sludge from a previous run to a secondary settling tank, where water is siphoned off the top of tank and sludge is removed from the bottom. Some of the sludge is used as inoculum for incoming primary effluent (activated sludge). The remainder of the sludge, **secondary sludge** is removed (Fig. 17.10), and the process derives its name from its inoculation with activated sludge. Vigorous development of heterotrophic microbes has taken place during the holding period. The populations include Gram-negative rods, predominantly *Escherichia, Enterobacter, Pseudomonas, Achromobacter, Flavobacterium* and *Zooglea* spp; other bacteria including *Micrococcus, Arthrobacter,* various coryneform and mycobacteria; *Sphaerotilus* and other large filamentous bacteria; and low numbers of filamentous fungi, yeasts and protozoa. Bacteria occur in free suspension and as flocs. The flocs are microbial biomass held together by slime. Due to

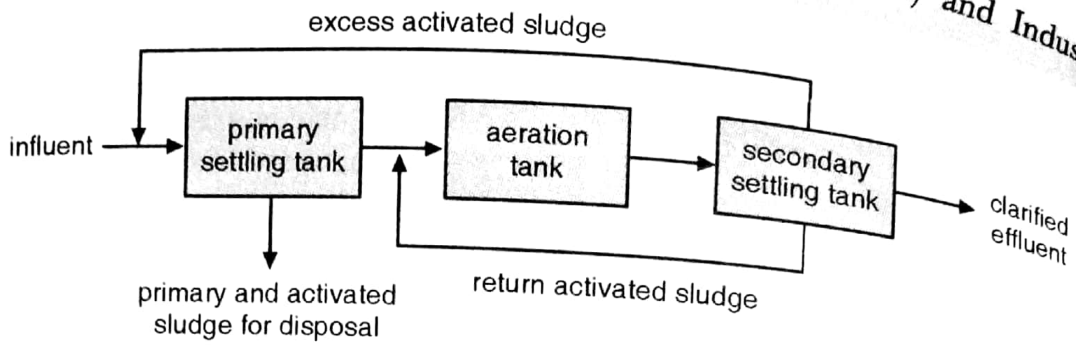

Fig. 17.10. Flow of materials through an activated sludge secondary sewage treatment system.

extensive microbial metabolism of the organic compounds in sewage, a large proportion of dissolved organic substrates is mineralised and another portion converted to microbial biomass. In advanced stage, biomass associated with flocs is removed by settling. Poor settling may cause **bulking** of sewage sludge caused by proliferation of filamentous bacteria like *Sphaerotilus, Beggiatoa, Thiothrix,* and *Bacillus* and filamentous fungi like *Geotrichum, Cephalosporium, Cladosporium* and *Penicillium.* A portion of the settled sewage sludge is recycled for use as the inoculum for incoming raw sewage, but the rest goes for additional treatment by composting or anaerobic digestion. Activated sludge process reduce the BOD of the effuent to 10–15% of that of the raw sewage. Intestinal pathogens are also reduced. Non–pathogenic bacteria proliferate in number.

An important characteristics of the activated sludge process is the recycling of a large proportion of the biomass. This results into a large number of microbes that oxidise organic matter in a relatively short time.

Non–conventional activated sludge process. In conventional process **nitrogen** and **phosphorus** are removed during tertiary treatment of sewage. Conventional activated sludge processes can be modified for removal of nitrogen and phosphorus employing biological rather than chemical processes. **Nitrogen,** by activated sludge process is removed by encouraging nitrification followed by dentrification. The conventional activated sludge system can be modified to encourage denitrification as follows :

Single sludge system. This comprises a series of aerobic and anaerobic tanks in lieu of a single aeration tank. Methanol or settled sewage serves as the carbon source for denitrifiers.

Multisludge system. Carbonaceous oxidation, nitrification, and denitrification are carried out in three separate systems. Methanol or settled sewage serves as carbon source for denitrifiers.

Bardenpho process. This consists of two aerobic and two anoxic tanks followed by sludge settling tank. Tank 1 (anoxic) is used for denitrification, with wastewater used as carbon source. Tank 2 (aerobic) is utilized for both carbonaceous oxidation and nitrification. Mixed liquor from this tank, which contains NO_3, is returned to tank 1. The anoxic tank 3 removes the NO_3 remaining in the effluent by denitrification. Finally tank 4 (aerobic) is used to strip the N_2 gas that results from denitrification, thus improving mixed liquor settling.

Phosphorus is removed by two systems.

A/O (aerobic/oxidation) process. The A/O process consists of an anaerobic zone (detention time 0.5–1 hr) upstream of the conventional aeration tank (detention time 1–3 hrs). Under anaerobic conditions, microbes release stored phosphorus to generate energy, which is used for uptake of BOD from sewage. When aerobic conditions are restored microbes exhibit phosphorus uptake levels above those normally required to support cell maintenance, synthesis etc. Excess phosphorus is stored as polyphosphates within the cell. The sludge containing the excess phosphorus is then wasted.

Bardenpho process. This also removes nitrogen as well as phosphorus by nitrification–denitrification process.

Tertiary treatment

This conventional treatment is deisgned to remove pollutants and mineral nutrients, especially N_2 and P salts by chemical process. Activated carbon filters are normally used in their removal from secondary–

treated effluents. To prevent eutrophication, phosphate is removed from sewage by precipitation as calcium, aluminium or iron phosphate. **Breakpoint chlorination** is a process to remove NH_3. In big cities, a highly advanced tertiary water treatment system integrates several of the tertiary treatment processes.

Modern large scale sewage treatment, however involves additional processing of sewage after tertiary treatment. This includes removal of pathogens, sludge processing, and landfarming.

Removal of pathogens

The subject of removal of pathogenic microbes by activated sludge and other waste water treatment processes has been reviewed from time to time. Enteric pathogens can be effectively removed by these processes. These include viruses, *Salmonella*, *Giardia* and *Cryptosporidium*. With progressive treatment of raw sewage, their numbers reduced significantly during successive steps, being almost completely eliminated in final treatments. When compared with other biological treatment as trickling filters, activated sludge process is relatively, efficient reducing the numbers of pathogens in raw sewage.

Sludge processing

The sludge or **biosolids** resulting from the various stages of sewage processes (both the primary sludge and the activated sludge generated by secondary processes) is also treated further for stabilization of their organic matter and reduction of water content. Primary sludge contains 3.8%, where as secondary sludge 0.5 to 2% solids. Organic matter stabilization prevents the odour formation and decreases the number of pathogens. Reduction of the water content reduces the weight of sludge making its transport easier.

Sludge treatment typically involves several steps (Fig. 17.11). **Thickening** reduces the volume of sludge. This is achieved by allowing the solids to settle in a tank or by centrifugation. **Digestion**, a microbial process results into stabilization of the organic matter and some elimination of pathogens due to higher temperatures. Sludge can be digested anaerobically as well as aerobically. **Anaerobic**

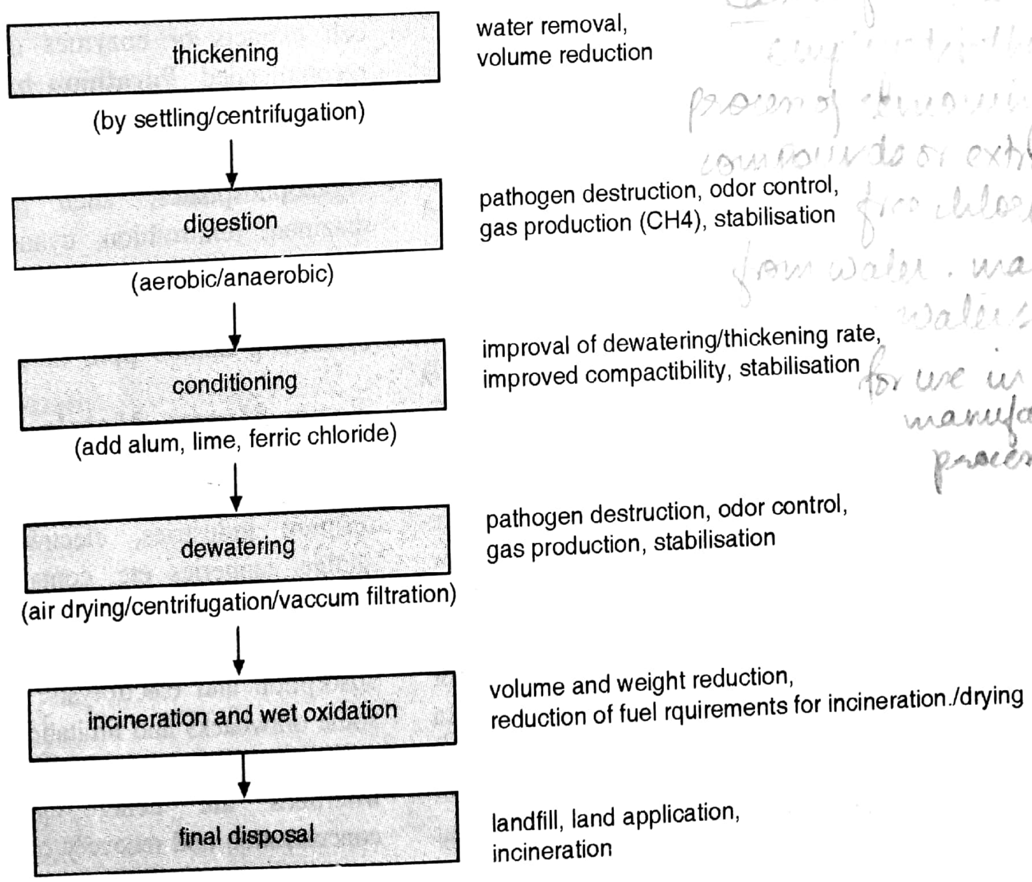

Fig. 17.11. Sludge treatment processes flow chart.

digestion is the most common treatment, extending over a period of 2–3 weeks in large covered tanks of sewage treatment facility. Methane is produced during this process, which can be used as energy source. Four groups of bacteria are involved during this complex process. For **aerobic digestion**, air is supplied in open tanks. Aerobic microbes degrade the sludge resulting in reduction of solids. Solids are reduced further during **conditioning** in which chemicals (alum, lime, ferric chloride) are added to aggregate suspended particles. This is followed by **dewatering**, achieved by several methods such as air drying, centrifugation or vaccum filtration.

Landfarming

This is the practice of disposing biosolids produced by waste water plants on agricultural land. The biosolids may be added to soil as solids or liquids. This practice adds nutrients and water to the soil. Liquid sludge can be injected into the soil from tanker trucks. Before adding to the soil, sludge may be treated by **processes which significantly reduce pathogens (PSRP)**. For application on land where food crops are grown, the sludge may be treated further by **processes to further reduce pathogens (PFRP)**.

Land Application of Wastewater

Although treated domestic wastewater is usually discharged into water bodies, it may also be disposed of via land application–sometimes for crop irrigation and sometimes as a means of additional treatment or disposal. The three methods used in the application of treated wastewater include, low rate irrigation, overland flow, and high–rate infiltration. With **low–rate irrigation**, sewage effluents are applied by sprinkling or by surface application. This is useful for small communities requiring large (5–6 hectares/1000 people) areas. In **overland flow** method, wastewater effluents are allowed to flow for a distance of 50–100 m along a 2–8% vegetated slope and are collected in a ditch. This is used for clay soils with low permeability and infiltration. In **high–rate infiltration,** also referred to as **soil aquifer treatment** (SAT) or **rapid infiltration extraction (RIX)** wastewater treatment is done at loading rate of more than 50 cm/ week (in overland flow method it is 5–14 cm/week, whereas in low–rate irrigation, 1.5 to 10 cm/week). The treated water, most of which has percolated through coarse textured soil, is used for groundwater recharge and may be recovered for irrigation. This system requires less land than low–rate irrigation or overland flow methods.

Biodegradation of Industrial Wastes

Industrial wastes chiefly include pesticides, toxic heavy metals, and petroleum and other hydrocarbons. Although, thus subject has already been considered elsewhere, a brief account is also being presented in this section.

Pesticide Waste

Microorganisms have been found very effective in **disposal of pesticide waste** through biodegradation. The excess pesticide wastes generated from pesticide industries effluents, and washings of pesticide containers are environmental problems. Microbes detoxify/degrade these wastes thus providing a safe method of their disposal. Instead of whole cells, cell extracts or enzymes of microbes have been recommended. **Parathion hydrolase** obtained from *Flavobacterium* ATCC 27551 and *Pseudomonas diminuta* can hydrolyse a number of organophosphates, such as methyl parathion, diazinon, fenitrothion, cyanephos and coumaphos. The process is very fast and requires no cofactors. *Pseudomonas cepacia* is used to clean up soil containing 20,000 ppm of 2,4, 5–T.

Toxic Heavy Metals

Wastes from thermal power stations, metal and refining industries, electroplating units, sewage sludge, tanneries etc, contain toxic heavy metals. These can be removed by physico–chemical means such as ion exchange, precipitation, activated carbon adsorption and electrolysis. But each of these has some drawbacks and limitations. Therefore, microbial biomass has been used for removal of heavy metals. Microbes are being exploited for removal concentration and recovery of these metals. Microbes adsorb these metals actively or passively. Bi... produced from Z...