Domestic Waste Water Treatment

Conventional sewage treatment plants are based on biological decomposition of nontoxic organic wastes, using bacteria. Such biological decomposition is conducted under aerobic conditions, *i.e.* in the presence of plenty of oxygen. For oxidation of 1 mg of carbon, 2.67 mg of dissolved oxygen DO is required. Organic hydrogen, sulphur and nitrogen, the major elements in waste water, consume additional oxygen for their oxidation.

$$\left.\begin{array}{l}\text{Organic wastes}\\(C, H, O, F, S)\end{array}\right\} + O_2 \xrightarrow{\text{Aerobic}} CO_2\uparrow + H_2O + H_2SO_4 + NH_4^+ + NO_3^- \qquad (16)$$

The solubility of O_2 in water is only 9 ppm (mg/L) at 20°C and less at higher temperature. The purity of water depends on the rate of transport of O_2 by aeration and on the total load organic material which requires oxidation. The organic load is expressed in terms of BOD *i.e.*, biochemical oxygen demand which means quantity in mg of O_2 needed to decompose the organic material in 1L waste water.

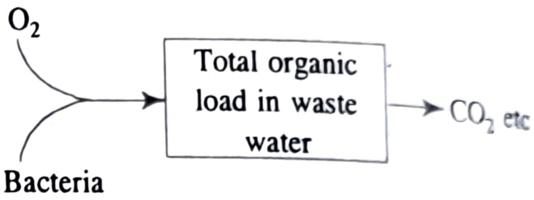


Fig. 7.6 Biochemical oxygen demand (BOD)

As a rough estimate, the BOD values (mg O_2/litre waste water) for various processes are:

Domestic sewage ,165; industrial waste water, 200; paper industry 372; food industry, 747; metal industry 13.

Evidently such a heavy load is likely to upset the capacity of most natural water bodies so that sewage treatment is essential for maintaining the water quality.

The processes commonly used for domestic sewage treatment are illustrated in Fig. 7.7. In the first stage solid wastes are removed from water by screening and any scum is removed, followed by the settling of sludge. In the second stage, the residual liquid is subjected to biological oxidation of soluble organic materials, through a bed of microbes in activated sludge. Finally, the solids are removed by sedimentation. The liquid effluent from such treatment has a much lower organic load which, after chlorination to kill pathogenic micro-organisms, may be mixed directly in lakes and streams.

In sewage treatment disposal of sludge is one of the major problems. The sludge can be spread on soil or landfills though the latter are becoming

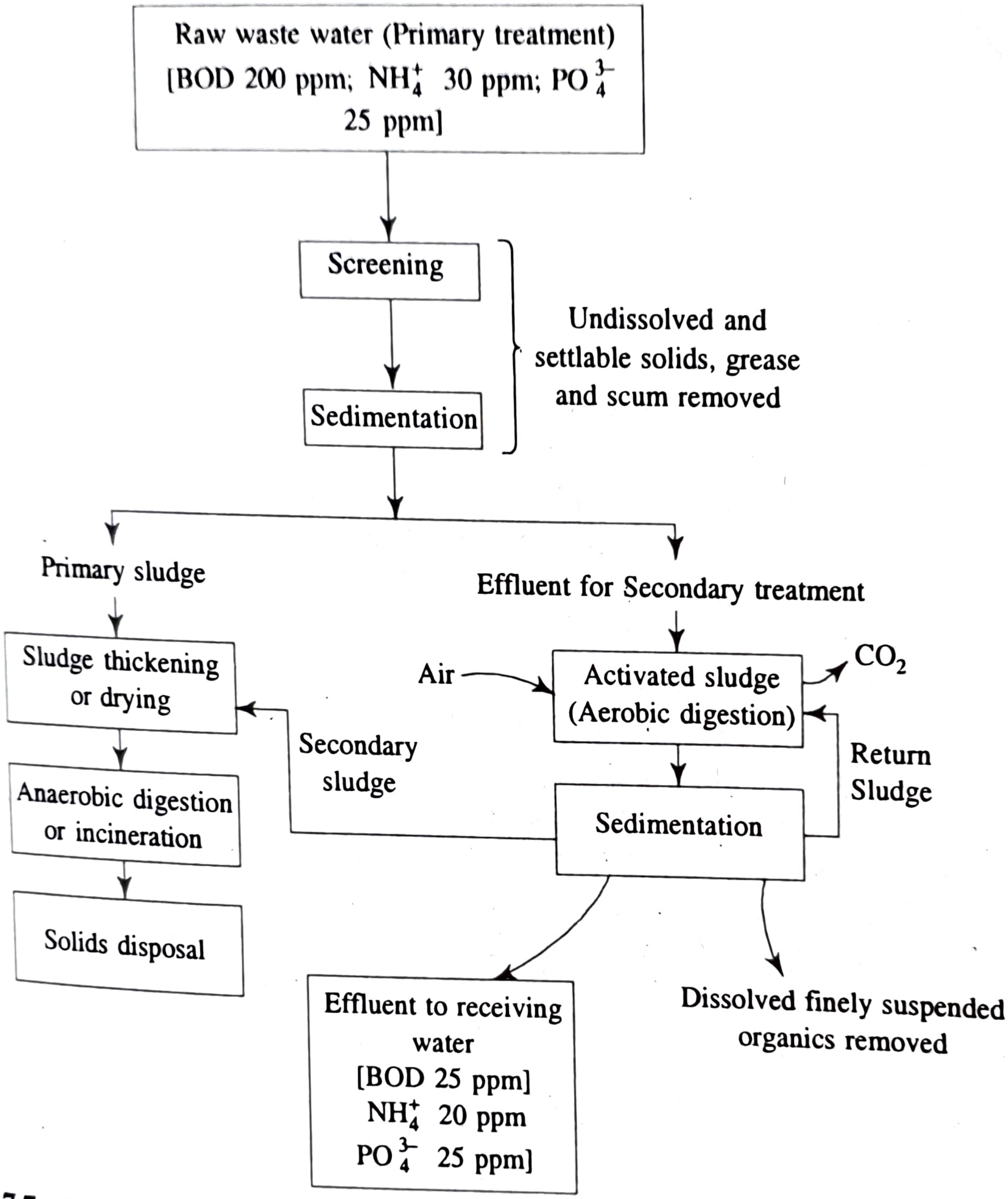


Fig. 7.7 Primary and secondary treatment of municipal waste water (Source: *Cleaning Our Environment*, American Chemical Society, Washington D.C., p. **107.** 1969)

scarce with increasing population. For localities near the shore, the sludge is usually dumped into the ocean, which, however, has a fragile ecosystem. In near future all kinds of ocean dumping should be stopped.

The sludge may be utilised as fertiliser on crop lands. However, the presence of toxic materials in the sludge is a snag in this respect. There are practices of incineration or pyrolysis of sludge but again there is the risk of contamination of air with the toxic pollutants emitted from the sludge. A safer procedure is anaerobic digestion sludge yielding CH_4.

The effluent (liquid) from secondary treatment plants has a lower BOD (25 mg/L). It has the compositionn: BOD 25 ppm, NH_4^+ 20 ppm and PO_4^{3-} 25 ppm (Fig. 7.7). For clear lakes this type of effluent will promote eutrophication. Removal of dissolved matter requires tertiary treatment which is discussed below.

The effluent from secondary treatment plant is introduced into a flocculation tank where $Ca(OH)_2$ (lime) is added to eliminate phosphates as $Ca_5(PO_4)_3(OH)$. From there the solution goes tȯ NH_3 stripping tower. Nitrogen present in waste water exists as NH_4 which is converted to gaseous NH_4^+ at high pH values (pH ≈ 11). The remaining organic materials are removed by adsorption on activated charcoal and finally chlorination is used for disinfection. The final effluent is fairly clean: BOD (1 ppm), PO_4^{3-} 0.2 to 1 ppm NH_4^+ 0.3 to 1.3 ppm a N. However, tertiary treatment plants are costly due to their high energy requirements. The main energy costs are for recycling CaO obtained from lime sludge by heating and operating the NH_3 stripping tower.

An alternative method for nitrogen removal is transformation to N_2 using a combination of nitrifying and denitrifying bacteria. The land may also be used as a natural filter for waste water. Soil particles absorb PO_4^{3-} and to less extent NH_4^+ and NO_4^{3-}. The presence of microbes in soil facilities biological oxidation of C and N. The possibility of spraying secondary effluents on forest or crop land has also been explored in some cases.

Aerobic Treatment Processes

These are secondary waste treatment methods by biological processes. After primary treatment for removal of insoluble matter *i.e.*, grit, grease, scum etc. and sedimentation, the resulting sludge is subjected to secondary treatment. As mentioned before in the aerobic treatment process the biodegradable organic matter is utilised by the bacterial cells (micro-organisms) for their growth and metabolism and in the process huge quantity of cell mass and CO_2 are generated. About 50% of biodegradable C present in the waste water is converted into cell mass and the rest into CO_2.

Among the available processes, the most important is the *Activated Sludge Process.* This is shown in Figure 7.8. It is a continuous flow flocculated growth process in which bacterial flocs (Activated sludge) are separated from treated effluent by a clarifier and recycled to the aeration tank to maintain a high degree of process intensity. The microbial cell matter which is formed as part of the waste degradation process is generally kept in the aeration tank till the micro-organisms reach their saturation

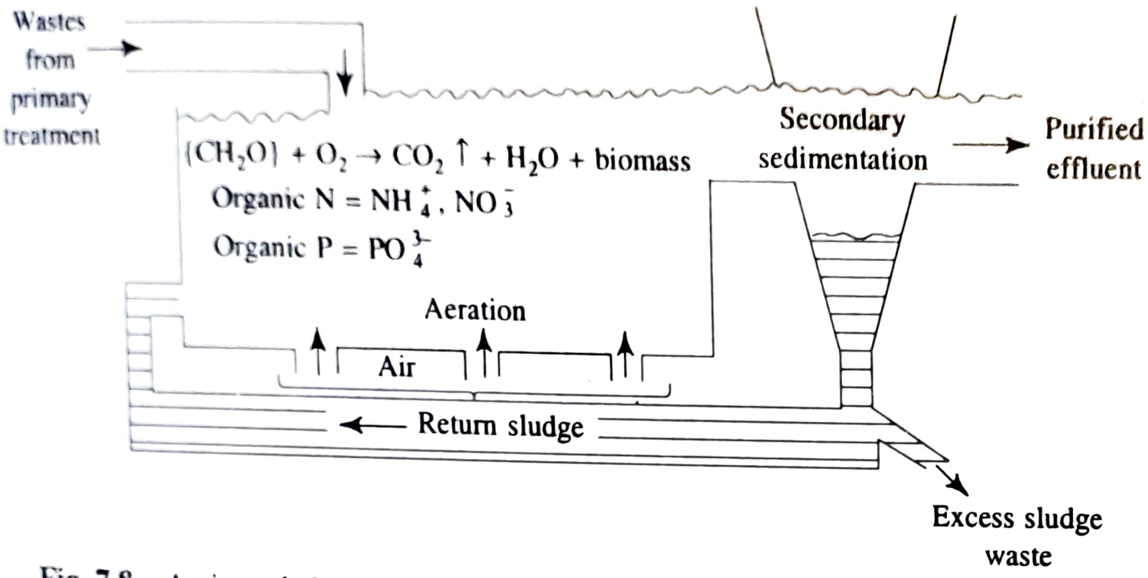


Fig. 7.8 Activated sludge system for secondary biological waste water treatment

point of growth when the cells flocculate well to form settleable solids. These solids settle out in a settler and part of it is discarded. The bulk of the solids, return sludge, is recycled to the bottom of the aeration tank and encounters the fresh sewage. The return sludge and the influent sludge provide optimum conditions for rapid degradation of organic matter.

Oxidative degradation is accomplished mostly by chemoheterotropic bacteria and cillated protozoa. Effective degradation is caused by predominant genera like *Pseudomonas*, *Zoogloea, Flavobacterium, Alcallgenes* etc. Nitrification in the activated sludge process (ASP) proceeds by the action of the general *Nitrosomonas, Nitrospira*, etc. in the first step and by nitrobacter, *Nitroscoccus* etc. in the second step. Denitrification takes place by the action of the genera *Pseudomonas, Microccus* etc.

$$2\,NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} H^+ + NO_2^- + H_2O$$

$$NO_2^- + \frac{1}{2}O_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$$

$$4NO_3^- + 5CH_2O + 4H^+ \rightarrow 2N_2\uparrow + 5CO_2\uparrow + 7H_2O$$

The merits of the ASP are (i) low-retention time and (ii) BOD removal up to 95%. The demerits of the ASP are: (i) low-strength waste, BOD 1500 to 2500 mg/L, (ii) energy is required for aeration, (iii) high-sludge production and (iv) disposal problem of activated sludge.

Another process is the *lagooning process*, the oldest process in the country. There are several types of this process; (a) aerobic lagooning, (b) anaerobic lagooning and (c) aerobic-anaerobic lagooning. These are illustrated in Figure 7.9.

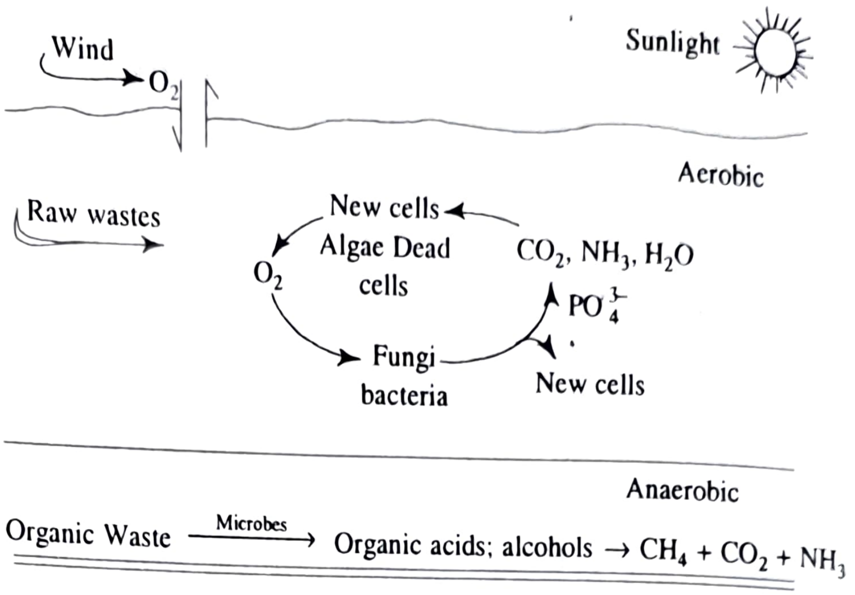


Fig. 7.9 Lagooning processes.

Anaerobic Treatment Processes

In these processes about 95% of biodegradable C is decomposed into biogass (c.f. 50% in aerobic process) and the rest 5% into biomass. Three main steps are involved in the breakdown of organic waste under anaerobic conditions.

$$\text{Organic waste} \xrightarrow[\text{Steps}]{\text{Hydrolytic}} \text{Organic acids, alcohol} \xrightarrow[\text{Steps } 35^\circ\text{C, pH 5 to 6}]{\text{Acetogenetic}}$$

$$\text{Acetic acid, } H_2, CO_2 \xrightarrow[\text{Steps } 45^\circ\text{C, pH 6 to 8}]{\text{Methanogenic}} CH_4, CO_2$$

These steps are essentially hydrolysis of biopolymers to monomers, fermentation of monomers to volatile acids and methanogenesis. The anaerobic degradation of carbohydrate takes place as follows: polysaccharide to pyruvate and pyruvate to lactic acid or ethanol. The microbial species responsible for anaerobic degradation are: *Actinomyces, Arthrobacter, Citrobacter, Escherichia, Lactobacillus, Micrococcus* etc.

Anaerobic treatment is illustrated in the flowsheet diagram on next page.

Upflow Anaerobic Sludge Bed (Blanket) Reactor (UASB) Process

The process has been developed by a group of scientists at Wageningen Agricultural University, Netherlands (G. Lettinga, L.W. Hulshoff Pol *et al*). It is based on the settleability of microbial flocs to produce a region at the bottom of the digester where very high-biomass concentration can be maintained. The effluent is fed in the bottom of UASB (Figure 7.11) into the base of the sludge blanket. The size of the flocs varies from 1 to 5 mm diameter and should have good settling characteristics. The loading

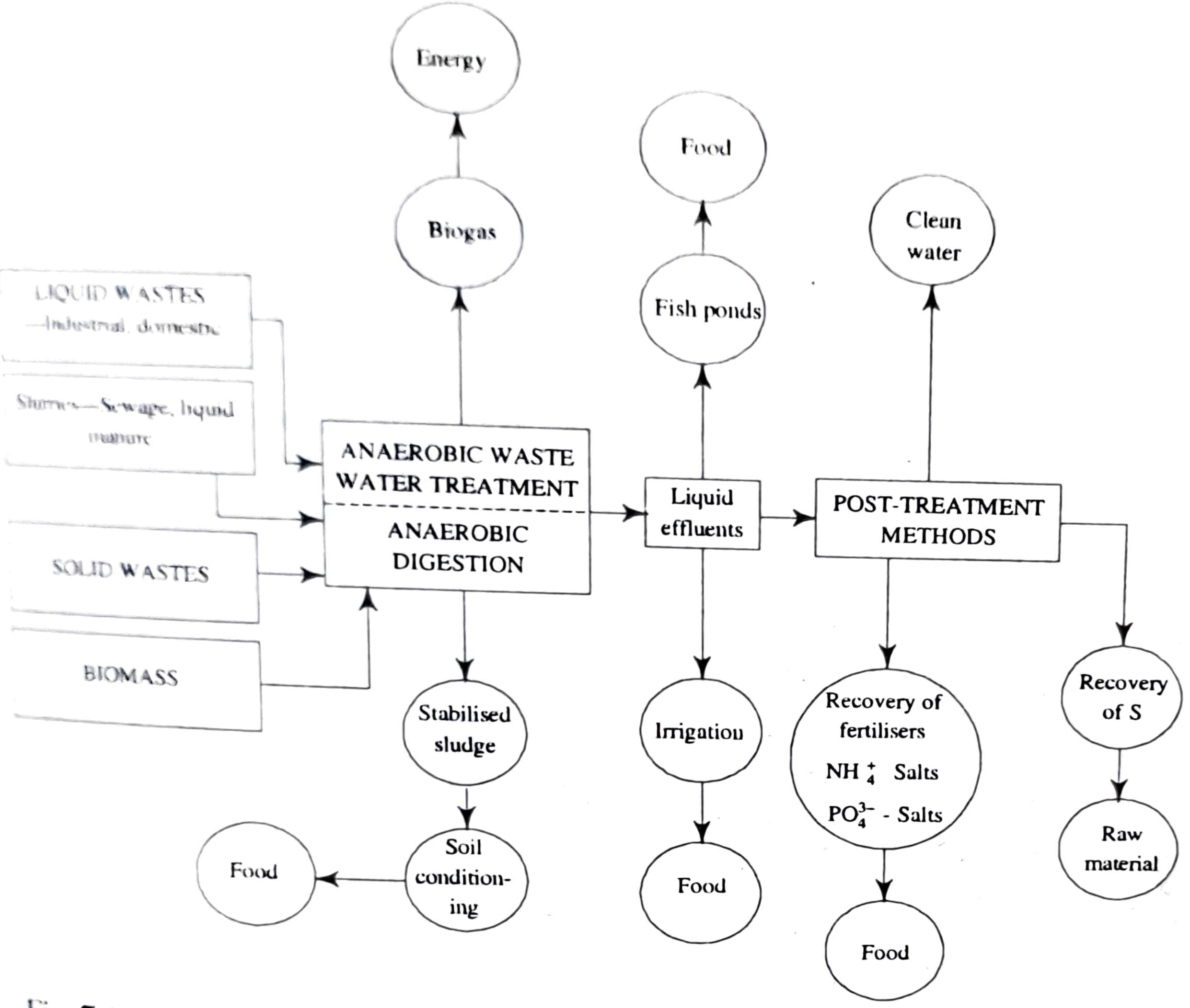


Fig. 7.10 Anaerobic digestion at the core of a treatment and recovery technology

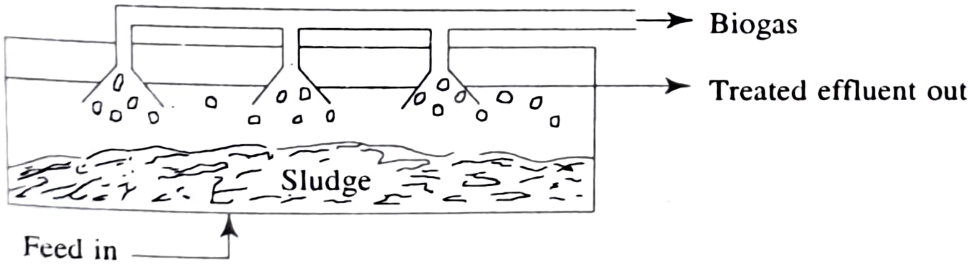


Fig. 7.11 Upflow Anaerobic Sludge Blanket Reactor (UASB)

rate is higher in comparison to other processes (19 kg COD $m^{3-}d^{-1}$). The UASB process satisfies the urgent need of developing countries for simple low-cost and integrated environmental protection system, which combine waste water treatment with recovery and reuse.

Anaerobic waste water treatment is preferred to other processes for the reasons: (i) cheaper than aerobic process in respect of treatment of medium and high-strength waste waters (COD 1500 mg L^{-1}) (ii) energy (biogas) is produced instead of wasted (iii) less space is required for anaerobic

hydrolysis org acid/alc
step
methogenic 45°c pH6-8 acetogenic 35°c pH 5-6
$CH_4 + CO_2$ $CH_3COOH + CO_2 + H_2O$

plant and (iv) relatively low-cost technology in terms of equipment. UASB can be considered as the core of a very promising environmental protection and resource recovery concept.

Industrial Waste Water Treatment

The toxic, nonbiodegradation chemical in industrial waste effluent can be purified by two methods: (1) filtration by activated charcoal/synthetic resins, and (2) membrane techniques.

1) Activated charcoal with large surface area is quite an effective filter medium for adsorption of organic molecules. Table 7.3 shows more than 99% reduction in the concentration of several chlorinated hydrocarbons in an effluent stream.

Table 7.3 Removal of some toxic chlorinated organics

Compound	Initial concentration (µg/l)	Concentration after activated charcoal treatment (µg/l)	Organic reduction (%)
Aldrin	48	<1.0	99+
Dieldrin	19	0.05	99+
Endrin	62	0.05	99+
DDT	41	0.1	99+
Arochlor 1242 (PCB)	45	<0.5	99+

D.G. Hager, *Chem. Eng. Progr.*, 72 (10)57(1976)

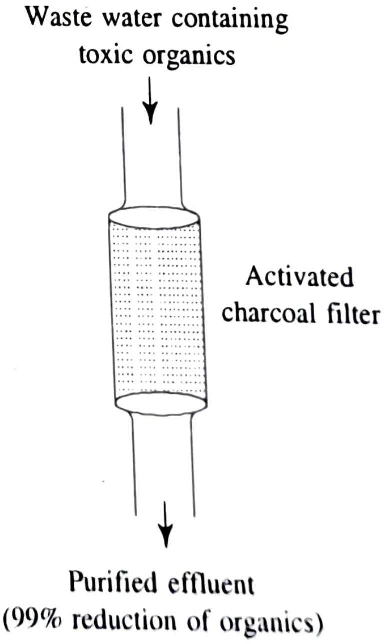
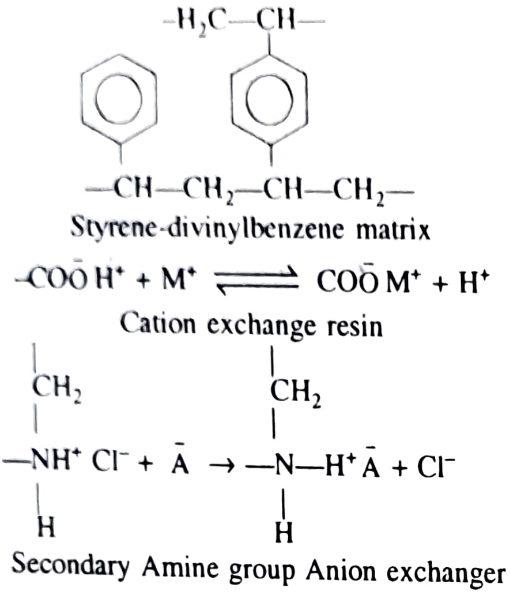


Fig. 7.12 Filtering industrial wastes with activated charcoal



Styrene-divinylbenzene matrix

$-COO^{-}H^{+} + M^{+} \rightleftharpoons COO^{-}M^{+} + H^{+}$

Cation exchange resin

$-NH^{+}(CH_2)(H)\,Cl^{-} + A^{-} \rightarrow -N(CH_2)(H)-H^{+}A^{-} + Cl^{-}$

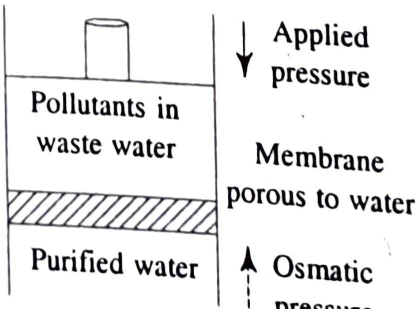
Secondary Amine group Anion exchanger

Fig. 7.12A Filtering industrial wastes by synthetic resins

Synthetic organic ion-exchange resins are very useful for removal of industrial waste chemicals. Thus, styrene-divinylbenzene co-polymer can remove chlorinated pesticides by adsorption at the surface, while cationic and anionic ion-exchange resins can eliminate ionic dyes from textile mill waste water.

The ion-exchange membrane finds an important application in the removal of toxic wastes by ultafiltration or reverse osmosis. In ultrafiltration, the solution is pushed under pressure through a membrane which contains pores of size 2 to 10,000 nm (20 – 10^5 Å) whereby big molecules are retained and the effluent that passes off is free of the big molecules. In reverse osmosis, the membrane pores are smaller—0.04 to 600 nm—in size. Both these techniques have found extensive application in purification of industrial waste water in metal, textile, paper and pulp and food industries.

Electrodialysis is another membrane technology which is used for the concentration of ions. Under an electrical field, anions migrate towards the anode and cations towards the cathode (Fig. 7.13). The cell contains membranes with fixed charge—negative or positive—whereby the membranes becomes impermeable to either



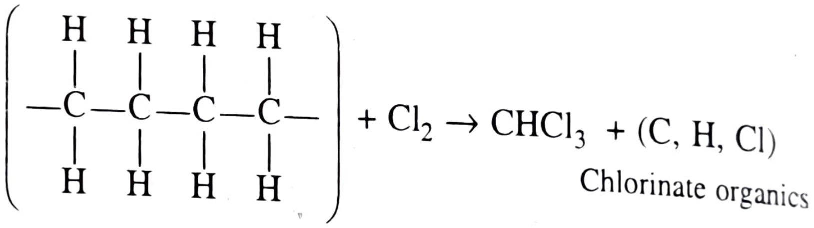
Membrane pore size:
2 to 10,000 nm (Ultrafiltration)
0.04 to 600 nm(reverse osmosis)

Fig. 7.13 Industrial waste water purification by the membrane technique of ultrafiltration or reverse osmosis anions or cations. This technique is useful for production of fresh water in arid coastal regions. In Japan electrodialysis of sea water is the principal source of salt. Among other important uses mention may be made of treatment of metal plating wastes, battery manufacture, glass etching and desalination of effluents.

3) Reverse Osmosis.

Drinking Water Supplies

Treatment of drinking water supplies is a matter of great public health importance. The water treatment plants are, in general, simpler than sewage treatment plants. They work in three steps: aeration to settle suspended matter, coagulation of small particles and suspended matter by lump and ferric chloride, and finally disinfection by chlorination to kill viruses, bacteria, etc. Recently, it has been discovered that chlorination gives rise to $CHCl_3$ and chlorinated organics, which are toxic, in drinking water, and also chloromines if ammonia is present in the water, an also chloromines, if ammonia is present in the water body. The permissible dose of $CHCl_3$ in drinking water has been fixed at 100 parts per billion by the Environmental Protection Agency (EPA) in USA. This limit can be enforced if the chlorinated water is subjected to activated carbon treatment, as shown in Fig. 7.14



$$\left(\begin{array}{cccc} H & H & H & H \\ | & | & | & | \\ -C- & C- & C- & C- \\ | & | & | & | \\ H & H & H & H \end{array}\right) + Cl_2 \rightarrow CHCl_3 + (C, H, Cl)$$

Chlorinate organics

Dissolved organics, humus, etc. in natural water

In France and Switzerland, chlorination has been replaced by ozonation—ozone is used to kill bacteria. Although ozone is free from the side reactions which occur during chlorination, it is expensive, in terms of energy consumption, and unstable as it rapidly changes into O_2.

7.5 TRACE ELEMENTS IN WATER

Several trace elements (few ppm or less) are found in polluted water. The most dangerous among them are the heavy metals e.g. Pb, Cd, Hg and metalloids e.g. As, Se, Sb, etc. As mentioned earlier, the heavy metals have a great affinity for sulphur and attack sulphur bonds in enzymes, thus immoblilising the latter. Other vulnerable sites are protein carboxylic acid (COOH) and amino ($-NH_2$) groups. Heavy metals bind to cell