Wastewater Treatment

6

Monika Asthana, Avnish Kumar, and B.S. Sharma

Contents

M. Asthana (✉) • A. Kumar
Department of Biotechnology, School of Life Sciences, Dr. Bhim Rao Ambedkar University, Khandari Campus, Agra 282004, UP, India
e-mail: mailtomonikasaxena@gmail.com

B.S. Sharma
Department of Environmental Studies, School of Life Sciences, Dr. Bhim Rao Ambedkar University, Khandari Campus, Agra 282004, UP, India

R.L. Singh (ed.), *Principles and Applications of Environmental Biotechnology for a Sustainable Future*, Applied Environmental Science and Engineering for a Sustainable Future, DOI 10.1007/978-981-10-1866-4_6

Abstract

Water is a universal solvent and a vital constituent of living organisms. It recirculates in the environment through the hydrologic cycle which can be hampered due to human activities in terms of pollution. Polluted water, known as wastewater or effluent, should not be drained without treatment, as it constitutes a serious threat to living beings. Parameters like biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), etc. are used to determine water quality. Therefore, wastewater treatment methods are targeted to get these parameters at optimum level. Such processes are either physicochemical or biotechnological in nature and may be categorised as preliminary, primary, secondary and tertiary treatments. All of these must be followed by disinfection to obtain potable water. Major objectives of preliminary and primary treatment include removal of coarse and fine particle by screening, filtration, sedimentation, equalisation and flotation. Secondary treatment consists of biological treatment, i.e. aerobic, anaerobic and specialised reactors. Tertiary treatment entails chemical processes to purify wastewater. In the future, as the world's population continues to grow, such research priorities will become increasingly paramount. At present, a change in research priorities can be observed, and new technologies that meet the requirements of sustainable development and multidisciplinary approach are being applied. Therefore, modified methods must be developed to be used in systemic combination to fulfil the demand of potable and reusable water.

Keywords

Activated sludge • Trickling filters • Rotating biological contactor • Anaerobic process/digesters • Aerobic processes

6.1 Introduction

Water is indispensable in the living world for many reasons. It is an essential constituent of photosynthetic process that is important to animal and plant ecosystems. It establishes itself as a means of nutrition for plants and forms the natural living conditions for many living species and acts as a solvent of organic and inorganic materials (universal solvent). It is also a vital constituent of living organisms. The amount of water contained in the human body represents about 65–70 % of the body weight. The protoplasm of most living cells contains approximately 80 % water, and any reduction of this amount can have damaging effects and may even be fatal. Thus, water plays an important role in metabolism and exists as necessary component of body fluids. Most biochemical reactions take place in the presence of water. It thus supports the entire system of life on our planet, constituting crucial elements for all ecosystems. In fact, the availability of water has governed the establishment of civilisations and the development and progress of man's economic activities.

6.1.1 The Earth's Water Resources

Water is in recirculation in the environment through the hydrologic cycle. This signifies the movement of water evaporated from surface waterbodies or evapotranspirated from plants to the atmosphere where it condenses and precipitates to the earth as rain, snow or in some other forms. On the surface of the earth, some of the precipitated water then runs off into streams, lakes, ponds and the sea. The rest percolates through soil strata to form groundwater aquifers that ultimately flow into surface waterbodies.

Although 70 % of the world's surface area is covered with water, only 0.00192 % of the total stock is available for human use because 98 % water occurs in oceans and seas and 1.998 % is locked up in arctic regions, glaciers, mountains and clouds and, thus, remains unavailable.

6.2 Wastewater

Wastewater may be defined as 'a combination of liquid or water – carried wastes removed from residences, institutions and commercial and industrial establishment together with such groundwater, surface water and storm water as may be present'. It is the used water supply of a community and consists of domestic waterborne wastes, called sewage, which include human excrement and wash water as well as everything that goes down the drain of a home and into a sewage system.

Most industries are water based and release a considerable volume of wastewater which is generally discharged into water courses either untreated or inadequately treated and causes water pollution (Noorjahan 2014). Industrial waterborne wastes usually contain acids, alkaline materials, oils, greases and animal and vegetable matters discharged by factories. Industrial growth encompasses setting up of new industries, producing new chemicals and biochemicals. Varied industries such as distilleries, tanneries, textiles, antibiotics, drugs and pharmaceuticals, pulp and paper, dairies, oil refineries, petrochemicals, fertilisers, organic chemicals, etc. in the process of manufacturing contribute to water pollution. Thus, all small-, medium- and large-scale industries have their own role in water pollution. Water pollution is also caused by solid and hazardous wastes dumped on land.

6.2.1 Problems Associated with Improper Wastewater Discharge

Generally, problems associated with improper wastewater discharge include the following:

(a) Wastewater affects natural water quality through the production of taste, odour and malodorous gases. The gases that may be produced include CO_2, H_2S, CH_4, NH_3 and other trace gases such as H_2 and N_2.

(b) Wastewater contains pathogenic microorganisms that cause many diseases.
(c) Wastewater sludge may introduce highly persistent detergents, pesticides and other toxic wastes and compound.
(d) Massive quantity of solids may produce objectionable and dangerous levels of sludge on the bottom of waterbodies or along their banks. These solids add to the chemical, biological and physical degradation of natural water courses.
(e) Wastewaters containing grease and oils render bathing sites unusable, present extra problems for treatment works, produce unsightly conditions and interfere with the process of biodegradation.
(f) Wastewater may produce eutrophication or the enrichment of water by plant nutrients, biomass of phytoplankton, attached algae, macrophytes, etc.

For the aforementioned reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, succeeded by proper treatment and final disposal, is not only desirable but also necessary for appropriate environmental sanitation.

6.3 Classification of Wastewater

The sources of origin and generation of wastewater may be grouped as follows:

(a) Domestic (Sanitary) Wastewater – Domestic wastewater includes discharges from residences and commercial, institutional and similar facilities.
(b) Industrial Wastewater – Industrial wastewater signifies the industrial waste generated from industrial localities. It varies with the type and size of the industry and other factors affecting production and processes.
(c) Infiltration/Inflow – Infiltration as a class of wastewater addresses extraneous water that enters the sewer system from the ground through various means. Likewise, it includes storm water that is discharged from sources such as roof leaders, foundation drains and storm sewers.
(d) Storm Water – Storm water refers to the water resulting from precipitation runoff.

6.4 Properties and Characteristics of Water and Wastewater

6.4.1 Physical Characteristics

6.4.1.1 Temperature

Temperature is one of the physical parameters that reveal a great deal of information about the water source and its state. Changes in temperature may be due to seasonal or daily variation or disposal of hot water or due to disposal of wastes from industrial processes and power stations (thermal pollution). Notable effects of temperature increase include:

(a) Speeding up and motivation of chemical reaction and reaction rate. The temperature may affect the reaction rate of microorganisms to the extent of doubling it for each 10 °C increase. Higher temperature can support the growth of undesirable aquatic plant and wastewater fungus.
(b) Reduction of dissolved oxygen concentration.
(c) Reduction of solubility of gases.
(d) An increase of biochemical oxygen demand (BOD).
(e) An increase in the rate of corrosion of substances.
(f) An increase in sensitivity of aquatic animals for toxic dissolved substances in the aquatic environment.
(g) An increase in malodour.

The change in temperature depends on the latitude and altitude of the earth too.

6.4.1.2 Turbidity

Turbidity is the phenomena whereby a specific portion of a light beam passing through a liquid medium is deflected from undissolved particles. Organic particles, oil, algae, colloidal and soluble substances present in water often initiate turbidity or colour in wastewaters. Small particles with density close to water may never settle and stabilise in the water. However, coagulation and flocculation of these particles into larger flocs are the necessary steps for their removal followed by sedimentation. Measurement of turbidity can be made easily and rapidly by using turbidimeters. Turbidity is an expression of optical property that causes light to be scattered and absorbed rather than transmitted in straight line through the sample. Measurements of turbidity in water can be defined in two ways: the turbidity resulting from 1 mg per litre of fuller's earth suspended in water or the depth of the column of water that just obscures the image of burning standard candle viewed vertically through the sample (Jackson candle unit, JCU)

1 nephelometric turbidity unit (NTU) $\simeq$ JCU

It is also measured by Beer-Lambert's law

$$A = \log_{10}\ [\mathrm{Io}/\mathrm{I}] = \varepsilon.c.l$$

Here,

ε is the molar absorbance coefficient.
c is the concentration of the solute in Moll^{-1}.
l is the light path of liquid in cell or cuvette in cm.

6.4.1.3 Taste

Usually, drinking water must be almost tasteless to please the consumer. The taste and odour are subjective properties which are rather difficult to measure. The presence of taste may be due to dissolved impurities organic or inorganic in origin. Examples of organic substances are phenols, chlorophenols, oils, fats, grease and unsaturated hydrocarbons. Inorganic substances include dissolved salts, iron, manganese, chlorides and gaseous substances such as hydrogen sulphide that are produced by decomposition of organic matter by microorganism such as fungi, algae, protozoa, bacteria, etc. These chemicals may be originated from municipal and industrial waste discharges, from natural sources such as decomposition of vegetables matters or from associated microbial activity. Taste and odour may also result from decaying aquatic vegetation as well as decaying leaves, weeds, grasses, etc.

Measurement of taste is rather difficult and classification generally included salty, bitter, sour or sweet. While it is relatively easy and safe for a person to evaluate the taste of drinking water supply, no one would be anxious to taste wastewater before or after conventional treatment. Production of potable water from unchlorinated effluent needs lime treatment, recarbonation, filtration, ion exchange, carbon absorption, ozonation, another carbon absorption treatment, reverse osmosis and finally chlorine dioxide treatment which make it costly.

6.4.1.4 Odour

A wholesale supply of water is odour-free. Existence of odour in water may be due to a number of reasons such as:

(a) Biodegradation of organic and inorganic compounds of nitrogen, phosphorus and sulphur
(b) Decomposition of algae and other microorganisms
(c) Generation of substances such as ammonia sulphide, chlorine, cyanide and hydrogen sulphide

It is easy to check for an odour associated with a drinking water supply. Offensive odours are generally associated with the raw wastewater that has been in the sewage system too long and aerobic conditions have developed. The sewage turns black and gives off hydrogen sulphide. The effects of this unpleasant odour include psychological stress, headache, nausea, vomiting, mental depression and blurred vision, fatigue or loss of appetite, impaired respiration, irritation of eyes, loss of sleep as well as reduction in production and work efficiency.

6.4.1.5 Colour

Sources of water colour include:

(a) Natural sources such as extracts from organic debris (leaves, wood and peats)
(b) Industrial origins such as mine waste, textile industry, paper industry and dye industry
(c) Domestic sewage

Pure water is colourless. True colour in natural water is caused by large organic molecules. Colour in water may also result from the presence of natural metallic ions such as iron oxide (causes red colour) and manganese oxide (causes brown and black colour). Other sources are humus and peat material, plankton, weed and industrial waste (e.g. textile and dye operation, paper and pulp production, food processing, chemical manufacturing, mining, refining and slaughterhouse operation). The greatest contribution of colour by plants is humic acid which produces a yellow brownish colour together with tanning and humate from the decomposition of lignin. These lignin derivatives are highly coloured and resist biological degradation.

6.4.1.6 Conductivity

Conductivity is a numerical expression of the tendency of an aqueous solution to carry an electric current. This ability depends on:

(a) First presence and type of ion
(b) Total concentration of ions
(c) Mobility, balance and relative concentration of ions
(d) Temperature of solution

Solutions of most organic acids, bases and salts are relatively good conductors. Electrical resistance, R (in ohms), of conductor may be derived as

$$R = R_s \times L / A$$

where

Rs = resistivity of conductor
R = resistance
L = length of conductor
A = cross-sectional area of conductor

The reciprocal of resistance is conductance expressed in reciprocal ohms or mhos.

$$R_d = 1 / R_s = \mathrm{Ac} / \mathrm{Rm}$$

where

Rs = specific resistance
Ac = cell constant
Rm = measured resistance

Conductivity may be defined as the electrical conductance of a conductor of unit length and unit cross-sectional area and commonly expressed in μmhoscm^{-1}.

Freshly distilled water has a conductivity of 0.5–2.0 μmhoscm^{-1}, increasing after a few weeks of storage to 2–4 μmhoscm^{-1}. The increase is mainly due to absorption of atmospheric CO_2 and to a lesser extent NH_3. Pure water is thus normally not a good conductor of electricity. Increase of dissolved salts in water increases its conductivity. As such, the conductivity of water is sometimes used for indicating the degree of its purification or pollution. The conductivity is proportional to the concentration of dissolved solids.

$$a.\text{EC} = \text{TDS}$$

where

EC = electrical conductivity
TDS = total dissolved solids
a = constant

6.4.1.7 Salinity

Salinity is the total dissolved solids in water after all carbonates have been converted to oxides, all bromides and iodides have been replaced by chlorides and all organic matter has been oxidised.

$$\text{Salinity(gm / kg)} = 0.03 + 1.805.\text{chlorinity(gm / kg)}$$

The sources of chlorides in natural water can be from:

(a) Leaching of chloride containing rocks and soils
(b) Salt water intrusion (coastal areas)
(c) Agricultural, industrial and domestic wastewater

6.4.1.8 Solid Content

Solid content is defined as the matter that remains as residue upon evaporation and drying at 103–105 °C. According to particle size, wastewater solids have been classified as indicated in Table 6.1.

6.4.1.8.1 Dissolved Solids

In potable water, these consist of inorganic salts and a small concentration of organic matter. Water with high dissolved solids is generally of inferior palatability and may induce an unfavourable physiological reaction in the consumer. Highly mineralised water is also unsuitable for many industrial applications.

Table 6.1 Solids classification system

Solids	Size ($\times 10^{-6}$m)
Settleable	>100
Super colloidal	1–100
True colloidal	0.001–1
Dissolved	<0.001

6.4.1.8.2 Suspended Solids

These may be inorganic particles such as clay, silt and other soil constitutes, or they may be of organic origin such as plant fibres and biological solids like algae, bacteria, etc. These are the solids that can be filtered out by a fine filter paper. Water high in suspended solids may be aesthetically unsatisfactory for such purposes as bathing. Suspended solids also provide adsorption sites for chemical and biological agents.

6.4.1.8.3 Volatile and Fixed Solids

They give a measure of the amount of organic matter present in a sample. The test is carried out by burning organic matter to convert it to carbon dioxide and water, at a controlled temperature of 550 °C, to prevent the decomposition and volatilisation of inorganic substances.

6.4.1.8.4 Settleable Solids

These are solids in suspension that can settle in quiescent conditions under the influence of gravitational attraction.

6.4.1.9 Density

The density of fluid is defined as its mass per unit volume.

$$\rho = \mathrm{m} / \mathrm{V}$$

For water at standard pressure 760 mmHg and at 4 °C the density is 1000 $\mathrm{Kgm^{-3}}$

The reciprocal of the density is termed as specific volume. It is defined as the volume of a fluid occupied by a unit mass of the fluid. The ratio of the weight (density, ρ_s) of a substance to the weight (density, ρ_w) of an equal volume of water at standard conditions is denoted as the specific gravity (s.g.)

$$\text{s.g.} = \rho_s / \rho_w$$

Since molecular activity and spacing increase with temperature, fewer molecules exist in a given volume of fluid as the temperature is increased. Therefore, density decreases with an increase in temperature. The application of pressure forces a larger number of molecules into a given volume. This results in an increase in density.

6.4.1.10 Radioactivity

Radiation is a characteristic feature of unstable atoms. Therefore, the approach to understanding radioactivity should begin at the level of atom. Certain nuclides spontaneously emit particles or gamma radiation or X radiation following orbital electron capture or undergo spontaneous fission.

Radioactivity may be of artificial, induced and natural types. Artificial radioactivity is a man-made radioactivity produced by particle bombardment or electromagnetic irradiation as opposed to natural radioactivity. Induced radioactivity is produced in substance after bombardment with neutrons or other particles. The resulting activity is naturally induced radioactivity if formed by nuclear reaction occurring in nature and artificially induced radioactivity if the reactions are caused by man. The property of radioactivity exhibited naturally by more than 50 radionuclides such as uranium, thorium, radium, polonium, etc. is known as natural radioactivity.

6.4.2 Chemical Characteristics

6.4.2.1 Hydrogen Ion Concentration (pH)

pH is a measure of the acidic or alkaline nature of a solution and affects the quality of a water or wastewater.

$$\mathrm{pH} = -\log[\mathrm{H}^+]$$

where $[H^+]$ is the concentration of hydrogen ions.

pH ranges from 0 to 14, with 7 as neutral, <7 being acidic and >7 being alkaline. It is an important parameter for both natural water and wastewater. The concentration range suitable for the existence of most biological life is narrow and critical. Wastewater with an adverse concentration of pH is difficult to treat by biological means, and if the concentration is not altered before discharge, the wastewater effluent may change the pH in natural water (Frobisher et al. 1974). Most microorganisms cannot survive below pH 4, but sulphate-oxidising bacteria can exist at pH 0.1. In practice, pH control is the most significant economic control the sanitary microbiologist has over the growth and death of microorganism.

6.4.2.2 Alkalinity

Alkalinity is the measure of buffering capacity of water. Alkalinity is caused primarily by chemical compounds dissolved from rocks and soil and is mainly due to the presence of hydroxyl, carbonate and bicarbonate ions. These compounds are mostly carbonates and bicarbonates of sodium, potassium, magnesium and calcium. Normally, wastewater is alkaline. In the anaerobic digestion process, sufficient alkalinity has to be present to ensure that the pH will not drop below 6.2, because the methane bacteria cannot function below that point. When digestion is proceeding satisfactorily, the alkalinity will normally range from 1000 to 5000 mg/l as $CaCO_3$.

Alkalinity in water is determined by titrating a sample of water with 0.02 N, H_2SO_4 solution. Total alkalinity is found by titrating to pH 4.5 (methyl orange end point) with a colour change from orange to pink.

$$\text{Alkalinity mg/l as CaCO}_3 = (A - B) \times N \times 50{,}000 / \text{ml sample}$$

where

A = ml standard acid used for sample
B = ml standard acid used for blank
N = normality of acid (0.02 N)

6.4.2.3 Acidity

Acidity is usually attributed to sample with a pH below the value of 7. In unpolluted water, acidity comes from dissolved CO_2 or organic acids leached from the soil. Atmospheric pollution may cause acidity. Acid water corrodes metal or concrete.

The acidity of water is determined by titrating a water sample with 0.02 N NaOH to pH 8.3.

Acidity as $\mathrm{mg\,CaCO_3/l} = [(A - B)\times C] - [(D\times E)]\times 50{,}000/\mathrm{ml\ sample}$

where

A = ml NaOH titrant used for sample
B = ml standard NaOH titrant used for blank
C = actual normality of standard NaOH titrant (0.02 N)
D = ml standard H_2SO_4 used
E = actual normality of standard H_2SO_4 (0.02 N)

6.4.2.4 Hardness

Hardness in water will prevent the formation of soap lather and is usually due to divalent cations such as Ca^{2+}, Mg^{2+}, Sr^{2+}, Fe^{2+} and Mn^{2+}. When hardness is numerically greater than the sum of carbonate and bicarbonate alkalinity, that amount of hardness equivalent to the total alkalinity is called carbonate hardness. The amount of hardness in excess of this is called non-carbonate hardness. When the hardness is less than or equals total alkalinity, all hardness is carbonate hardness and non-carbonate hardness is absent.

Hardness, $[\mathrm{mg\,equivalent\,CaCO_3/l}] = 2.497\mathrm{Ca}^{2+}[\mathrm{mg/l}] + 4.118\mathrm{Mg}^{2+}[\mathrm{mg/l}]$ (Rice et al. 2012).

When alkalinity < total hardness, carbonate hardness = alkalinity [mg/l].

Alkalinity > total hardness, carbonate hardness = total hardness [mg/l].

Impact of hardness includes:

(a) Economic losses to water uses through consumption of soap.
(b) Formation of precipitates on hot water appliances, boilers, kettles and domestic appliances, bath tubs, sinks, dishwashers and washbasins.
(c) Staining of clothes, dishes and other household utensils.
(d) Residues of the soap precipitate may remain in pores of skin making it feel rough and uncomfortable.
(e) Development of laxative effect on new consumers, especially due to the presence of $MgSO_4$.

The total hardness of water sample can be easily determined by the EDTA titrimetric method.

6.4.2.5 Dissolved Oxygen

Oxygen dissolved in sewage or water is needed for the maintenance of aerobic conditions, but the solubility of the oxygen in water is low. Drinking water saturated with oxygen has a pleasant taste, while water lacking dissolved oxygen has an insipid taste.

$$C_g = P_g.MW / R_uT$$

where

Cg = gas concentration in gas phase (g/m^3)
Pg = partial pressure of respective gas in gas phase [$Pa = N/m^2$]
MW = molecular weight of gas
Ru = universal gas constant (8.3143 J/K.mol)
T = absolute temperature (K)

Oxygen is slightly soluble in water. The actual quantity of oxygen that can be present in solution is governed by solubility of gas, partial pressure of gas in atmosphere, temperature and purity of water.

6.4.2.6 Oxygen Demand

Oxygen demand is the amount of oxygen needed to stabilise organic water.

(a) Biochemical oxygen demand (BOD) is a measure of amount of pollution by organic substances in water.
(b) Permanganate value (PV) is the chemical oxidation of water sample using a potassium permanganate solution.
(c) Chemical oxygen demand (COD) is the chemical oxidation of water sample using a mixture of concentrated H_2SO_4 and $K_2Cr_2O_7$.

$$PV < BOD < COD$$

6.4.2.7 Dissolved Gases

Natural water contains dissolved gases with varying concentration depending upon their solubility in water. When water is anaerobic and microbial activity exists, free ammonia, hydrogen sulphide and methane may exist. In the latter case the water needs to be oxygenated before use. From the point of view of water purity, the most important gases are oxygen and CO_2.

6.4.2.8 Chloride

Sources of chloride in natural water include leaching of chloride from rocks and soils; salt water intrusion (in coastal areas); agricultural, industrial, domestic and human wastewaters; and infiltration of groundwater into sewers adjacent to salt water. Chloride in the form of Cl^- ions is one of the major inorganic anions in water and wastewater. In potable water, the salty taste produced by chloride concentration is variable and depends on the chemical composition of water. Some waters containing 250 mg/l chloride have a detectable salty taste if the cation involved is Na^+ ion. On the other hand, the typical salty taste may be absent in water containing as much as 1000 mg/l Cl^- when predominant cations are calcium and magnesium (Rice et al. 2012).

The chloride concentration is higher in wastewater than in raw water because NaCl is a common part of diet and passes unchanged through the digestive system. When chlorine dioxide is used in water treatment (disinfection), chlorite ion is formed as a by-product. Chlorite is known to cause methaemoglobinaemia [a condition in which haemoglobin of the blood is oxidised to a metabolically inactive (ferric) state].

6.4.2.9 Nitrogen

In waters and wastewaters, nitrogen exists in four main forms, and biological treatment cannot proceed unless some of these forms are present:

(a) Organic nitrogen N is organically bound in the tri-negative oxidation state. Organic nitrogen includes such natural materials as proteins, peptides, nucleic acids, urea and numerous synthetic materials.

$$\text{Total oxidised nitrogen} = \text{nitrite nitrogen} + \text{nitrate nitrogen}$$

(b) Ammonia NH_3-N is present naturally in surface and wastewaters. Its concentration generally is low in groundwater because it adsorbs to soil particle and clays and is not leached readily from soil. It is produced largely by deaeration of organic nitrogen-containing compound and by hydrolysis of urea.
(c) Nitrite NO_2-N is an intermediate oxidation state of nitrogen. It can enter a water supply system through use as a corrosion inhibitor in industrial purpose water. Nitrite is the actual etiologic agent of methaemoglobinaemia. Nitrous acid, which is also formed from nitrite under acidic conditions, can react with secondary amine to form nitrosamines, many of which are known to be carcinogens.
(d) Nitrate NO_3-N is derived from the oxidation of ammonia. High concentration of nitrate (>10 mg/l) in water can cause cyanosis in infants. Nitrate is an essential nutrient of many photosynthetic photoautotrophs and in some cases has been identified as a growth-limiting nutrient.

6.4.2.10 Toxic Metals

Toxicity is the adverse effect a substance has on a test organism exposed to that substance. Toxicity is the result of a concentration and time exposure test, modified by variables such as temperature, chemical form and availability. Toxicity may be:

(a) Acute (short-term lethal)
(b) Chronic (long-term effects that may be related to changes in appetite, growth, metabolism, reproduction and even death or mutations)

The degree of toxicity depends upon the element involved such as copper, lead, silver, chromium, arsenic and boron. These metal(loid)s have to be taken into consideration when designing biological treatment system. The presence of other trace metals such as nickel, manganese and mercury at high concentrations also interferes with wastewater treatment processes. Toxic anions such as cyanide and chromates, often found in industrial wastewater, also hinder biological treatment and should be removed by pretreatment at the source before discharge to the municipal sewage system.

6.4.2.11 Nutrients

Nitrogen and phosphorus are essential growth factors together with other trace elements like iron, potassium, magnesium, calcium, cobalt, copper, sulphur and zinc. If wastewaters are to be treated by biological processes, the nutrient balance has to be considered in order to establish optimum operating conditions.

6.4.2.12 Proteins

Proteins are nitrogenous organic substances of higher molecular weight found in the animal kingdom and to a lesser extent in the plant kingdom. The amount present varies from a small percentage in watery fluids (e.g. tomatoes) and in the fatty tissue of meat to quite a high percentage in beans and lean meats. Protein consists wholly or partially of very large numbers of amino acids united by peptide links. They contain carbon, hydrogen, oxygen, nitrogen, sulphur and sometimes phosphorus.

It has been shown that proteinaceous materials constitute a large part of the wastewater sludges and that the sludge particles, if they do not consist of pure protein, are covered by a layer of protein which governs their physical and chemical behaviour. Under the influence of microorganisms, proteins undergo decomposition, giving end products which often have objectionable foul odours.

6.4.2.13 Oil and Greases

Oil and grease compounds are insoluble in water but dissolve in such organic substances as petroleum, chloroform, ether, etc. These are esters of alcohol or glycerol and fatty acids. Fats are among the more stable organic compounds and are not easily decomposed by bacteria. However, they can be attacked by mineral acids resulting in the formation of glycerin and fatty acids.

When grease is encountered in sufficient quantities, it causes clogging of filters, nozzles and sand beds. It coats the walls of sedimentation tanks and on decomposing increases the amount of scum. If grease is not removed before discharge of wastewater, it can interfere with the biological processes in the surface waters and create unsightly floating matter. Both trickling filters and activated sludge process are adversely affected by grease which can coat the biological forms sufficiently to interfere with oxygen transfer from the liquid to the interior of living cells.

6.4.2.14 Carbohydrates

Carbohydrates are organic substances that include starch, cellulose and sugars. They contain carbon, hydrogen and oxygen. Carbohydrates may be grouped as simple sugar (monosaccharides) or complex sugars (disaccharides and polysaccharides).

Bacteria utilise carbohydrates for the synthesis of fats and proteins as well as for energy. The majority of carbohydrates in wastewater are in the form of large molecules that cannot penetrate the cell membrane of microorganisms. It should be noted that formation of organic acids (anaerobic respiration) in large quantities can overtax the buffering capacity of wastewater resulting in a drop in pH and a cessation of biological activity.

6.4.2.15 Phenols

Phenols are a group of aromatic compounds with one or more hydroxyl group attached to the benzene ring. Phenols can be recovered from coal tar while greater amounts are manufactured synthetically. Phenols in wastewater may be industrial in origin, such as from coal, gas or petroleum operations. Phenols cause taste problem in drinking water, particularly when the water is chlorinated. This is due to the formation of chlorophenol.

6.4.2.16 Detergents

Detergents are large organic molecules. They are slightly soluble in water and may cause foaming in wastewater treatment plants and in the surface water into which the wastewater effluent is discharged. They can also seriously reduce the oxygen uptake in biological treatment processes. Synthetic detergents are classified as anionic, cationic or nonionic due to their electrical charge or lack of one when they dissolve in water (Frobisher et al. 1974). Synthetic detergents are used in households and industry. Detergents affect the wastewater treatment adversely as they lower the surface or interfacial tension of water and increase its ability to wet surfaces with which they come in contact; emulsify grease and oils and deflocculate colloids; induce floatation of solids and give rise to foams; and may kill useful bacteria and other living organisms.

6.4.2.17 Biochemical Oxygen Demand

BOD determination involves the measurement of the dissolved oxygen consumed by microorganisms in the biochemical oxidation of organic matter. The test determines the appropriate quantity of oxygen that will be required to biologically stabilise the organic matter present. Advantages of the test include:

(a) Determination of the size of waste treatment facilities
(b) Measurement of the efficiency of some treatment processes
(c) Determination of the approximate quantity of oxygen needed for the stabilisation of organic matter present

Biological oxidation is a slow process and theoretically takes an infinite time to go to completion. Within a 20-day period, the oxidation is about 95–99 % complete, and in the 5-day period used for the BOD test, oxidation is 60–70 % complete. The 20 °C temperature used is an average value for slow-moving streams in temperate climates and is easily duplicated in an incubator. Different results would be obtained at different temperature because biochemical reaction rates are temperature dependent. The test requires exclusion of light during the incubation period to prevent oxygen formation by alga in the sample.

6.4.2.17.1 BOD Kinetics

Waste management studies are usually done using calibrated and verified water quality models. Dissolved oxygen (DO) in rivers results from the combined effect of aeration and oxidation of organic matter. A commonly used one-dimensional steady-state mathematical model to predict DO level in the rivers receiving organic matter can be written as (Thomann and Mueller 1987)

$$D = \mathrm{DO}e^{-\mathrm{kat}} + [\{K_d \mathrm{Lo} / (K_a - \mathrm{K}_r)\}(e^{-\mathrm{Krt}} - e^{-\mathrm{Kat}})] \\ + [\{K_n \mathrm{Lno} / (K_a - \mathrm{Ln})\}(e^{-\mathrm{Knt}} - e^{-\mathrm{Kat}})] \quad (6.1)$$

where DO is the initial oxygen deficit, Lo is the ultimate carbonaceous biochemical oxygen demand (CBOD) in the river after mixing, Lno is the ultimate nitrogenous biochemical oxygen demand (NBOD) in the river after mixing, *Ka* is the re-aeration rate coefficient, *Kr* is the BOD removal rate coefficient and *Kd* is the river CBOD deoxygenation rate coefficient, *Kn* is the NBOD deoxygenation rate coefficient and '*t*' is the travel time in the river. *Ka* can be determined by using different empirical relationships.

These calibrated and verified DO models are used to determine the required degree of wastewater treatment to maintain DO standards to meet the specific use of the waterbody. The models can then be used to formulate river water quality management strategies.

The rate coefficients *Kr*, *Kd* and *Kn* are related to the oxygen sink and depend upon the nature of the wastewater and other physical, chemical and biological factors particular to the river. *Kr* is the removal rate of carbonaceous organic matter and is determined from river surveys and is equal to

$$K_r = K_d + K_s \quad (6.2)$$

where *Ks* is the removal rate due to settling. *Kd* may be considered to consist of a component (*K*), characteristic of the type of wastewater, and can be determined from the analysis of long-term BOD measurements. Significant portion of particulate BOD is removed up to the secondary level treatment (i.e. suspended solids <30 mg/L); therefore, for such effluents, *Ks* in Eq. (6.2) may be neglected. The other component is 'ϕ', the characteristic of the conditions in the river, and may include factors that are not included in long-term BOD analysis. These components can be related to each other as

$$K_d = K + \phi \quad (6.3)$$

Wastewaters from urban areas are a mixture of carbohydrates, proteins and fats and vary in nature. With respect to biodegradation, their value changes with the level of treatment as readily biodegradable organic matter is first consumed. As such, the *Kr*, *Kd* and *Kn* which represent the biokinetic rates in rivers also change with the level of treatment. Bhargava (Bhargava 2008) developed a composite model considering the effect of settleable BOD for a river receiving wastewater from multiple outfalls by relating the rate constants with discrete and flocculent settling types.

The exertion of BOD is a first-order reaction kinetics and may be expressed as

$$\text{Rate} = \text{dBODr} / dt = -K_1\text{BOD}_\text{r}$$

where

t = time, days
BODr = amount of BOD remaining at time t
$k1$ = first-order reaction rate, 1/day

Integrating the above expression between the limits of UBOD and BODt and t = 0 and $t = t$ yields

$$\text{BODr} = \text{UBOD}(e^{-k1t})$$

where UBOD = total or ultimate carbonaceous BOD, mg/L

The amount of BOD exerted at time t (what gets regulated) is

$$\text{BODt} = \text{UBOD} - \text{BODr} = \text{UBOD} - \text{UBOD}(e^{-k1t})$$
$$= \text{UBOD}(1 - e^{-k1t}) r\, r\, k\, \text{BOD}\, dt\, \text{dBOD}\, \text{r}$$

The higher the concentration of waste matter in wastewater, the stronger it is said to be. Wastewater strength is most often judged by its BOD or COD.

Limitations of the BOD test include:

(a) A high concentration of active acclimated seed bacteria is required.
(b) Pretreatment is needed when dealing with toxic wastes, and effects of nitrifying organisms must be reduced.
(c) Only the biodegradable organics are measured.
(d) The test does not have stoichiometric validity after the soluble organic matter present in solution has been used.
(e) An arbitrary long period of time is required to obtain results.

Perhaps the most serious limitation is that the 5-day period may or may not correspond to the point where the soluble organic matter that is present has been reduced. This reduces the usefulness of the test results.

6.4.2.18 Chemical Oxygen Demand

The COD test involves an acid oxidation with potassium dichromate. A measured amount of dichromate is added, the acidified samples is boiled for 2 h, cooled and the amount of dichromate remaining is measured by titration with a 0.25 N solution of ferrous ammonium sulphate, using ferroin indicator for end point determination. COD results are generally higher than BOD values since the test oxidises material such as fats and lignin which are only slowly biodegradable.

6.4.3 Biological and Bacteriological Characteristics

6.4.3.1 Environmental Microbiology

Environmental microbiology is a growing field of biology which often brings together issues of concern to engineers, geologists, hydrologists, microbiologists and public health officials.

Microbes are nature's decomposers. Drinking water is obtained either from surface sources such as rivers and lakes or from underground water. Such natural waters are likely to be polluted with domestic and industrial wastes. Although water purification systems envisage protection from pollution, sometimes the water supply can become a potential carrier of pathogenic organisms and endanger public health. A number of diseases such as cholera, typhoid, viral hepatitis, etc. are known to be waterborne. These pathogens are commonly transmitted through drinking water and cause infection of the intestinal tract. It is, therefore, necessary to employ treatment facilities to purify water and to provide safe drinking water (potable water).

Water can be perfectly clear in appearance and free from odour and taste and yet be contaminated by microorganisms. Pathogenic organisms enter into water through sewage contamination or discharges from animals or humans into the reservoirs. The coliforms (*E. coli* and related organisms), *Streptococcus faecalis* and *Clostridium perfringens* which are normal inhabitants of the large intestine of animals and humans enter water supplies through faecal contamination. The presence of any of these bacterial species in water is evidence of sewage or faecal pollution. Techniques are available by which the presence of these specific groups can be easily identified. The routine bacteriological examination consists of (i) plate count to determine the number of bacteria present and (ii) biochemical test to reveal the presence of coliform bacteria since these are indicator organisms for faecal contamination.

A variety of other bacteria and organisms which may not be serious pathogens including faecal streptococci, slime-forming bacteria, sulphur bacteria, algae, etc. may also cause problems of odour, colour and taste, and it is essential that these are eliminated from the drinking water.

It is important therefore that the fundamental activity of microorganisms and their metabolic and biochemical control should be more fully understood by those who are involved.

6.4.3.2 Bacteria

The word bacteria comes from a Greek word meaning rod or staff, a shape characteristic of many bacteria. Bacteria are single-celled microscopic organisms that multiply by binary fission. In order to multiply, they need carbon obtained from carbon dioxide if they are autotrophs or from organic compounds (dead vegetation, sewage, meat) if they are heterotrophs. Their energy comes either from sunlight if they are photosynthetic or from chemical reaction if they are chemosynthetic. Bacteria are present in air, water, earth, rotting vegetation and the intestines of the animal. Bacteria are fundamental to all biological processes, especially in the degradation of organic matter which takes place in trickling filter, activated sludge processes and sludge digestion.

The bacterial communities found in wastewater treatment plants are complex. The bacterial flora of all aerobic treatment systems is basically the same and includes *Zoogloea*, *Pseudomonas*, *Chromobacter*, *Achromobacter*, *Alcaligenes* and *Flavobacterium*.

6.4.3.2.1 Facultative Bacteria

Most of the bacteria that absorb the organic material in a wastewater treatment system are facultative in nature. This means they are adaptable to survive and multiply in either anaerobic or aerobic conditions. The nature of individual bacteria is dependent upon the environment in which they live. Usually, facultative bacteria will be anaerobic unless there is some type of mechanical or biochemical process used to add oxygen to the wastewater. When bacteria are in the process of being transferred from one environment to the other, the metamorphosis from anaerobic to aerobic state (and vice versa) takes place within a couple of hours. When mixed cultures are present, aerobic and facultative bacteria first decompose organic matter, gradually depleting the dissolved oxygen. When dissolved oxygen is exhausted, facultative bacteria continue to use O_2 in the form of SO_4 and NO_3, while some facultative and anaerobic organisms produce organic acids, alcohol, methane, etc.

6.4.3.2.2 Anaerobic Bacteria

Anaerobic bacteria (*Methylococcus*, *Desulfovibrio*, *Clostridium*, *Thiobacillus denitrificans*, *Enterobacter*, etc.) live and reproduce in the absence of free oxygen. These carry on fermentation activity using organic substances as electron donors and acceptors. They produce organic acids, alcohol and least amount of energy.

$$\text{Organics} \rightarrow \text{Organic acid} + H_2O + CO_2 + \text{Energy}$$

If methane-producing bacteria are present, then the anaerobic digestion process is completed by converting organic acids into methane and CO_2.

$$\text{Organic Acids} \rightarrow CH_4 + CO_2 + \text{Energy}$$

Some anaerobic bacteria use nitrate and sulphate as an electron acceptor.

$$\text{Organics} + NO_3 \rightarrow (\text{Microorganism})N_2 + CO_2 + \text{Energy}$$
$$\text{Organics} + SO_4 \rightarrow (\text{Microorganism})H_2S + CO_2 + \text{Energy}$$

H_2S is given out by sulphate-reducing bacteria if the wastewater becomes anaerobic. Slightly acidic gas is absorbed in water. Sulphur bacteria can tolerate even pH 1.0 and oxidise H_2S to H_2SO_4.

$$H_2S + O_2 \rightarrow H_2SO_4 + \text{Energy}(\textit{Thiobacillus})$$

H_2SO_4 reacts with lime in concrete to form calcium sulphate which lacks structural strength.

In order to remove a given amount of organic material in an anaerobic treatment system, the organic material must be exposed to a significantly higher quantity of bacteria and/or detained for a much longer period of time. A typical use for anaerobic bacteria would be in a septic tank. The slower metabolism of the anaerobic bacteria dictates that the wastewater should be held several days in order to achieve even a nominal 50 % reduction in organic material. That is why septic tanks are always followed by some type of effluent treatment and disposal process. The advantage of using the anaerobic process is that electromechanical equipment is not required. Anaerobic bacteria release hydrogen sulphide and methane gas, both of which can create hazardous conditions. Even as the anaerobic action begins in the collection lines of a sewer system, deadly hydrogen sulphide or explosive methane gas can accumulate and be life-threatening.

6.4.3.2.3 Aerobic Bacteria

Aerobic bacteria (*Azotobacter*, *Pseudomonas*, *Nitrosomonas*, *Nitrobacter*, hydrogen-oxidising bacteria, etc.) live and multiply in the presence of free oxygen. Facultative bacteria always achieve an aerobic state when oxygen is present. While the name 'aerobic' implies breathing air, dissolved oxygen is the primary source of energy for aerobic bacteria. The metabolism of aerobes is much higher than that of anaerobes. This increase means that up to 90 % fewer organisms are needed compared to the anaerobic process or that treatment is accomplished in 90 % less time.

$$\text{Organic matter} + O_2 \rightarrow (\text{Aerobic condition}) H_2O + CO_2 + \text{Biomass} + \text{Energy} (\text{e.g. } \textit{Escherichia coli} \text{ reaction in wastewater})$$

Aerobic procedures are biochemically efficient and rapid. Their by-products are chemically simple and highly oxidised like CO_2 and H_2O. Iron bacteria occur normally in mine wastewater which is iron-rich. They can also occur in wastewater. They also contribute to corrosion and clogging of iron pipes.

$$Fe^{2++}O_2 \rightarrow Fe^{3++}\text{Energy}(\textit{Leptothrix})$$

Concrete pipes can collapse if they become too weak due to corrosion problem. Vitrified clay or PVC may be used to overcome the corrosion problem. Sewers can be lined with corrosion-resistant coating.

Aerobic procedures provide a number of advantages including a higher percentage of organic removal. The by-products of aerobic bacteria are carbon dioxide and water. Aerobic bacteria live in colonial structures called floc and are kept in suspension by the mechanical action used to introduce oxygen into the wastewater. This mechanical action exposes the floc to the organic material while treatment takes place. Following digestion, a gravity clarifier separates and settles out the floc. Because of the mechanical nature of the aerobic digestion process, maintenance and operator oversight are required.

Autotrophic Aerobes Autotrophs do not use organic matter. They oxidise inorganic compounds for energy and use CO_2 or CO_3 as carbon source. In wastewater treatment, autotrophs are relatively less important if high organic matter is the problem. Nitrifying bacteria, sulphur bacteria and iron bacteria are particularly important. Nitrifying bacteria oxidise ammonia.

$$NH_4^+ + O_2 \rightarrow NO_2^- + \text{Energy}(\textit{Nitrosomonas})$$
$$NO_2 + O_2 \rightarrow NO_3^- + \text{Energy}(\textit{Nitrobacter})$$

Conventional biological wastewater treatment generates large amounts of low-value bacterial biomass. The treatment and disposal of this excess bacterial biomass, also known as waste activated sludge, account for about 40–60 % of the wastewater treatment plant operation cost.

6.4.3.3 Fungi

Fungi are tiny aerobic, heterotrophic Protista containing no chlorophyll. They can tolerate dryer and more acidic conditions than most bacteria. They live in the earth, freshwater and sea water. Many grow as filaments and may be seen in polluted rivers, trickling filters and activated sludge. The optimum pH for most types is between 2 and 9. Because fungi are wholly aerobic, they can, in animals, exist only on the skin or in the bloodstream or lungs. Consequently, there are relatively very few fungi that cause disease in humans. Many organic substances can be attacked by fungi such as cellulose, phenols and hydrocarbons. Attacked organic compounds are converted into simple compounds which can be used as nutrients by other organisms. They produce aflatoxins that are harmful to man and animals. Fungi produce biomass with a higher value that can significantly change the economics of wastewater treatment. The biomass produced during fungal wastewater treatment has, potentially, a much higher value than that from the bacterial activated sludge process. The fungi can be used to derive valuable biochemicals and can also be used as a protein source. Various high-value biochemicals are produced by commercial cultivation of fungi under aseptic conditions using expensive substrates. Food-processing wastewater is an attractive alternative as a source of low-cost organic matter and nutrients to produce fungi with concomitant wastewater purification. Some species of fungi *Bjerkandera adusta*, *Aspergillus niger*, *Penicillium*, *Rhizopus arrhizus*, *Rhizopus oryzae*, etc. are useful in various sewage treatments.

6.4.3.4 Algae

Algae form a large group in the Protista. Being photosynthetic, they are classified as plants. Algae are single-celled or multicellular autotrophs. At night, some algae consume oxygen by chemosynthesis. Thus, water containing algae has a diurnal variation in dissolved oxygen. However, during sunlight, the carbon dioxide concentration falls. The CO_2 originated from the symbiotic relation with bacteria or from bicarbonates releases hydroxyl ion which tends to raise the pH of water: $HCO^{3-} \rightarrow CO_2 + OH^-$. Photosynthetic reaction during the day can be represented by the following reaction: $CO_2 + H_2O + \text{Sunlight} \rightarrow CH_2O + O_2$. This process utilises CO_2. The utilisation of CO_2 during the day may lead to a considerable rise of pH and results in a softening of water due to precipitation of $CaCO_3$, as represented by the following reaction: $Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2$. For most waste stabilisation ponds to function properly, algae such as *Chlamydomonas*, *Chlorella* and *Euglena* are needed to supply oxygen to aerobic heterotrophic bacteria that consume and oxidise the organic matter in sewage. The history of the commercial use of algal cultures spans about 75 years with application to wastewater treatment and mass production of different strains such as *Chlorella* and *Dunaliella*. The most important classes of freshwater algae are *Chlorophyta*, *Euglenophyta*, *Chrysophyta* and *Cyanophyta*. Biotreatment with microalgae is particularly attractive because of their photosynthetic capabilities, converting solar energy into useful biomasses and incorporating nutrients such as nitrogen and phosphorus causing eutrophication (Abdel-Raoufa et al. 2012). The other frequently found algae are *Ankistrodesmus*, *Scenedesmus*, *Oscillatoria*, *Micractinium* and *Golenkinia*.

In drinking water, algae are troublesome because they clog filters, may leave a taste when they die and produce toxin that can poison cattle. Algae in reservoirs can be reduced by oxygenating the water and reducing its CO_2 content or by adding an algicide such as copper sulphate or potassium paramagnet or by destratification of lake or reservoir. Algae growth in the catchment area of water supply system may lead to obnoxious taste and other odour problem that are hard to remove and may require treatment with activated carbon.

6.4.3.5 Protozoa

Protozoa are single-celled eukaryotic organisms. Some protozoa are parasitic organisms that are present in municipal sewage so are present in the treatment tanks. Such organisms are disease-causing agents, so part of the treatment of sewage is aimed to kill these organisms, e.g. *Cryptosporidia* and *Giardia*. Some protozoa scavenge and digest bacteria, and these are important for controlling bacterial pathogens as well as the overgrowth of other bacteria in a treatment system, e.g. *Paramecium* and *Vorticella*. Protozoa may indicate, by their type, the condition of activated sludge. They are also important in the operation of trickling filters. They feed on the bacteria and some utilise alga. Most protozoa are harmless and only a few cause illness in humans. *Entamoeba histolytica* (amoebiasis), *Giardia lamblia* (giardiasis), *Trypanosoma* (trypanosomiasis: sleeping sickness) and *Plasmodium* (malaria).

6.4.3.6 Rotifers

Rotifers are tiny aerobic creatures ranging from 50 to 250 μm in length; rotifers are the simplest of the multicelled invertebrate animals. They have cilia around their mouth and can swallow bacteria or other organic matter. Their presence in an effluent indicates highly efficient aerobic biological treatment. These organisms are important to wastewater treatment because their main source of food is bacteria. It is believed that rotifers scavenge free-floating bacteria, thus reducing BOD and also the numbers of pathogenic organisms in the water.

6.4.3.7 Crustaceans

Crustaceans mainly are water animals that use O_2, consume organic substances and have a hard body or crust. They are an important food for fish. Crustaceans are not normally found in the biological treatment processes. Usually they are an indicator of clean water. The metabolic complexity of the crustaceans limits their growth to relatively stable streams and lakes.

6.4.3.8 Worms and Larvae

Worms and larvae are the normal inhabitant in organic mud and biological slime. They have aerobic requirements but can metabolise solid organic matter not readily degraded by other microorganisms. The common organism used in stream pollution studies as indicators of pollution are the worm, tubifex and the midge fly larva of Chironomidae.

6.4.3.9 Viruses

A virus is an entity that carries the information for its replication but does not possess the machinery for such replication. Thus, all viruses are obligatory parasite and they are unable to reproduce outside a host cell. Viruses are disease-causing agents that are present in sewage and are removed during sewage treatment by adsorption to the floc. Some kind of floc or support is necessary to prevent washout of the active cells. A rich carbon source is a benefit in that it allows the formation of extracellular polymers which provide a glue-like substance to allow organisms to stick together (floc) or to a solid support. Viruses of particular interest in drinking water are hepatitis A, Norwalk-type viruses, rotaviruses, adenoviruses, enteroviruses and reoviruses.

6.5 Impact of Pollutants on Biotreatment

Industrial effluents may have a different impact on microorganisms depending on the nature and composition of effluent pollutants. This can be as follows.

6.5.1 Biodegradation

Biodegradation is nature's way of recycling wastes or breaking down organic matter into nutrients that can be used and reused by other organisms. Biodegradation is a process of biological catalytic reduction in complexity of chemical compounds using living microbial organisms (Asthana et al. 2014; Gupta et al. 2014; Kumar et al. 2015; Marinescu et al. 2009). There is, therefore, complete compatibility between the bacterial floral and oxo-biodegradable degradation of compounds. The term is often used in relation with ecology, waste management, environmental remediation (bioremediation) and for plastic materials, due to their long life span.

6.5.1.1 Inhibition of Biodegradation

Heavy metals like Cd, Cr, Cu, Hg, Zn, Ni, Pb, etc. are often present in a variety of industrial effluents and will inhibit biological activity. The presence of metals and metalloids will not allow otherwise degradable organic matter also to get degraded. Among organic solvents, chlorinated organics and alcohols are toxic to biological processes. Also phenols, pesticides and surfactant are inhibitory to biological activities in treatment plants.

Anaerobic processes are susceptible to sulphides (H_2S). High sulphides are present in the effluents of molasses fermentation industry, tanneries, petrochemical industry and paper mills. Anaerobic processes are also sensitive to pH outside the range of 6.5–8.2. Volatile fatty acids in excess of 2000 mg l^{-1}, NH_4^+ concentration in excess of 3000 mgl^{-1} and free ammonia at a concentration of 150mgl^{-1} are also very toxic.

6.5.2 Incidental Removal

Incidental removal of pollutant may occur by absorption, adsorption, precipitation and consequential concentration into sludge produced. Activated sludge has the capacity to bind heavy metals by polysaccharides of microbial flocs. Incidental removal of organic compounds by association with settleable solids or floatable scum or grease also takes place. This may occur if the compounds are insoluble or slightly soluble in water or hydrophobic.

6.5.3 Co-metabolism

When a particular compound is altered chemically by microbial metabolism without that compound serving as a source of carbon or energy, that compound is said to be co-metabolised or co-oxidised. A co-metabolite does not support the growth of organism concerned, and end products of transformation are accumulated stoichiometrically. The transformation does not require energy consumption. Co-metabolism is thought to occur because some enzymes produced by organisms for metabolism of their major carbon source are not substrate specific and can act on other compounds (Table 6.2). The rate of co-metabolism is often quite slow.

Table 6.2 Growth substrate and co-metabolite for some microorganisms

Organism	Growth substrate	Co-metabolite
Methylococcus	Methane	Ethane
Achromobacter	Hexadecane	Ethylbenzene
	Benzoic acid	3-chlorobenzoate
Nocardia	Hexadecane	Toluene
Corynebacterium	Hexadecane	Glucose
	Naphthalene	Anthracene

In pure culture, co-metabolism can be considered as a dead end transformation without benefit to that microorganism. Synergistic transformation and substrate utilisation may lead to recycling of relatively recalcitrant compound.

Co-metabolism appears to be an important route for the degradation of hydrocarbon, especially the more recalcitrant alicyclic compound in the environment. It is also an important pathway for pesticide degradation.

6.6 Wastewater Treatment Process

Selection of a treatment process depends on the characteristics of wastewater (i.e. form of pollutants like suspended, colloidal or dissolved; biodegradability; toxicity of the components), required effluent quality, cost, availability of treatment devices and area (land). Wastewater treatment units can be classified according to their capacity.

Small Wastewater Treatment Plants Small wastewater treatment units address wastewater treatments as applied to individual household or small community. Usually they are on-site treatment and disposal units.

Large Wastewater Treatment Units Large wastewater treatment plants are wastewater works that govern the discharge and treatment of large population sector. Sewage is collected from different localities and diverted to a central treatment plant.

Reasons for Treatment

The major reasons for the wastewater treatment may be as follows:

- Reduction in the spread of communicable diseases – to be achieved through the elimination or reduction of pathogens in the sewage
- Prevention or reduction of pollution that may enter the surface or groundwater sources
- Stabilisation of sewage without causing any odours or nuisances and without endangering the public health
- Water reuse aspects or for waste by-product recovery

Typical Strategies of Wastewater Treatment Processes

Wastewater may be treated on site or as sewage treatment works (STW) by the following methods:

Preliminary treatment
Physical (primary) treatment
Secondary treatment
Tertiary treatment (chemical)
Disinfection of wastewater

6.6.1 Preliminary Treatment

Preliminary treatment is used essentially to prepare wastewater for treatment. The objective of preliminary treatment is the removal of coarse particles and other large materials often found in raw wastewater, which could obstruct flow through the plant or damage equipment. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment units. These materials are composed of floating objects such as rags, wood, faecal material and heavier grit particles.

Elements that could damage treatment units are removed, and usually the flow is equalised, reducing maximum flow conditions and allowing a smaller plant treat the wastewater flow. A typical pretreatment unit contains the following.

6.6.1.1 Bar Racks

A bar rack (or bar screen) traps debris as wastewater influent passes through. Typically, a bar screen consists of a series of parallel, evenly spaced bars or a perforated screen placed in a channel used to remove large objects that could damage other plant devices (Singh et al. 2012). Large floating objects can be removed by passing the sewage through bars spaced at 20–60 mm. Retained material is raked from the bars at regular intervals. Bar screens with relatively large openings of 75–150 mm are provided ahead of pumps, while those ahead of sedimentation tanks have smaller openings of 50 mm.

6.6.1.2 Grit Chamber

These are designed to remove grit (inert dense material, such as sand, broken glass, silt, pebbles) from wastewater, to keep it from eroding and damaging pumps and other mechanisms. Preliminary treatment operations typically include coarse screening and grit removal of large objects. Sufficiently high velocity of water flow is maintained in grit chambers, or air is used, so as to prevent the settling of most organic solids.

6.6.1.3 Equalisation Basin

Most treatment devices must be designed with specific conditions of maximal and minimal flow, but normally the wastewater flow from a community is far from being constant. So, in order to keep the wastewater flow entering the primary treatment unit constant, an equalisation basin is used to collect and store wastewater flow. From this basin the wastewater is pumped at a constant rate into the primary treatment unit.

6.6.2 Primary Treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids and the removal of materials that will float (scum) by skimming. Approximately 25–50 % of the incoming biochemical oxygen demand (BOD_5), 50–70 % of the total suspended solids and 65 % of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus and heavy metals associated with solids are also removed during primary treatment, but colloidal and dissolved constituents are not affected. Pathogen removal during primary treatment is highly varied with various removal rates reported for different organisms.

6.6.2.1 Screening

Screening is the first operation at any wastewater treatment works. This process essentially involves the removal of large non-biodegradable and floating solids that frequently enter a wastewater works, such as rags, papers, plastics, tins, containers and wood.

Efficient removal of these constituents will protect the downstream plant and equipment from any possible damage, unnecessary wear and tear, pipe blockages and the accumulation of unwanted material that will interfere with the required wastewater treatment processes. The screening equipment is designed for efficient and cost-effective solution with durable and dependable operations.

Wastewater screening is generally classified into either coarse screening or fine screening.

6.6.2.1.1 Coarse Screens

Coarse screens remove large solids, rags and debris from wastewater and typically have openings of 6 mm (0.25 in.) or larger. Types of coarse screens include mechanically and manually cleaned bar screens, including trash racks (Fig. 6.1).

6.6.2.1.2 Fine Screens

Fine screens are typically used to remove material that may create operation and maintenance problems in downstream processes, particularly in systems that lack primary treatment. Typical opening sizes for fine screens are 1.5–6 mm (0.06–0.25 in.). Very fine screens with openings of 0.2–1.5 mm (0.01–0.06 in.) placed after coarse or fine screens can reduce suspended solids to levels near those achieved by primary clarification.

Most modern wastewater treatment plants utilise a combination of coarse and fine screening (i.e. upstream coarse screens providing protection to downstream fine screens).

6.6.2.2 Equalisation

For sewage treatment plants of small community, where wastewater flow rates vary considerably with time, and for industrial wastewater treatment plants, where wastewater flow and characteristic vary with time, equalisation becomes essential to obtain proper performance of the treatment plant by avoiding shock loading (hydraulic and organic) to the systems. Due to possibility of variation in flow rate received at treatment plant, there may be deterioration in performance of the treatment plant. To facilitate maintenance of uniform flow rate in the treatment units, flow equalisation is used. Equalisation can also be used to provide continuous

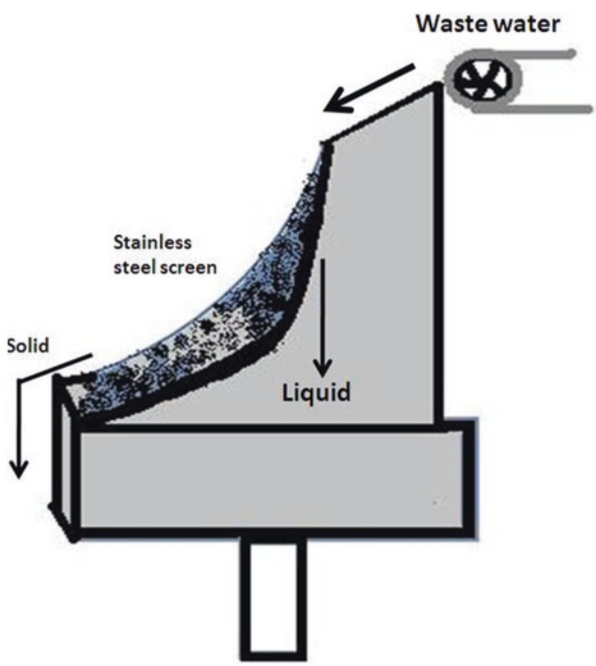


Fig. 6.1 Diagram of an inclined or tangential screen

feeding to the treatment system when the wastewater generation is intermittent, to control pH fluctuations or to control toxic concentration in the feed to the biological reactor, and this can also be used to control the discharge of industrial effluent in to the sanitary sewers.

Equalisation can be of two types:

(a) Inline: where all flow passes through equalisation basin.
(b) Offline: where the flow above average daily flow is diverted to equalisation basin. The pumping is minimised in this case, but the amount of pollutant concentration damping is considerably reduced.

Location of equalisation: Location of equalisation basin after primary treatment and before biological treatment is appropriate. This arrangement considerably reduces problem of sludge and scum in the equalisation basin. If the equalisation basin is placed before primary treatment, it must be provided with sufficient mixing to prevent deposition of solids and concentration variations and aeration to prevent odour problem. Most commonly used submerged or surface aerators have power levels of approximately 0.003–0.004 KW/m^3. In diffused air mixing, air requirement of 3.74 m^3/m^3 (air flow rate to water flow rate) is used.

6.6.2.3 Sedimentation

After removal of the coarse materials, sewage passes to sedimentation tanks, which aims to remove the settleable solids (represent up to 70 % of the total settleable solids) by gravity. A well-designed sedimentation tank can remove 40 % of the

BOD in the form of settleable solids. Sedimentation is used to remove suspended solids present in wastewaters. In fishery wastewaters, these include fish scales, portions of fish muscle and offal (relative proportions varying with the particular process being used).

Sedimentation is based on the difference in density between the bulk of the liquid and the solid particles, which results in the settling of the solids present. The terms sedimentation and settling are often used interchangeably. This operation is conducted as part not only of the primary treatment but also in the secondary treatment for separation of solids generated in the biological treatments such as activated sludge or trickling filters. Depending on the properties of solids present in the wastewater, sedimentation can proceed as:

- Discrete settling, if the wastewater is relatively diluted and the particles do not interact.
- Flocculent settling, if the particles that coalesce or flocculate are living particles of larger mass and faster settling rate. This is typical of untreated wastewater and is encountered in primary settling facilities.
- Zone settling, which is also called hindered settling and occurs when the particles adhere together and settle as a blanket, forming a distinguishable interface with the liquid above it. This reaction occurs in secondary clarifiers for sludges of biological treatments.

Each case has different characteristics. For discrete settling, calculations can be made on the settling velocity of individual particles. In a settling tank, these move both downwards (settling) and towards the outlet zone with the waterflow (Fig. 6.2). The particles that reach the bottom before the outlet will be separated from the effluent while the rest will pass through the settling tank. The critical velocity (*vc*) below in which a particle will be carried out of the tank is given by the depth of liquid (*d*), the volume of the tank (*V*) and the flow rate (*Q*):

$$v_c = d / (V / Q)$$

The ratio of *V*/*Q* is also known as the residence time of the liquid in the tank. It is called the overflow rate when *vc* is expressed in terms of volume of effluent per unit

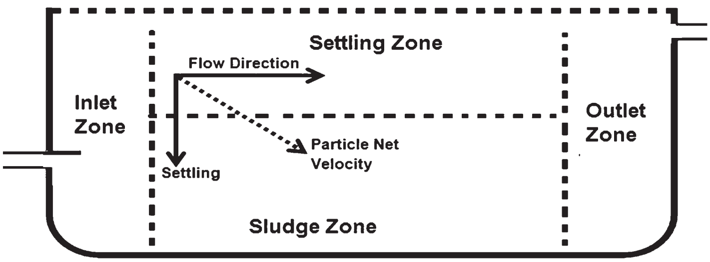


Fig. 6.2 Schematics of discrete settling

surface area of the tank per unit of time. This case may be present in fishery wastewaters but is not the most common.

In the case of a flocculant suspension, the formation of larger particles due to coalescence depends on several factors, e.g. the nature of the particles and the rate of coalescence. A theoretical analysis is not feasible due to the interaction of particles which depends among other factors on the overflow rate, the concentration of particles and the depth of the tank.

A settling column is used to evaluate the settling characteristics of a flocculant suspension (Fig. 6.3). The same kind of column using only one sampling port can be used to study discrete settling.

The zone (or hindered) settling, which occurs when the particles do not settle independently, is also studied by batch tests. In this case, an effluent that is initially uniform in solid concentration (Fig. 6.4), if allowed to settle, will do so in zones, the first of which is that of clarified water (1) and below is the interfacial zone (2) in which the solid concentration is considered uniform. In the bottom, a compact sludge develops in the so-called compaction zone (4). Between (2) and (4), a transition zone (3) generally exists.

In some cases, further compaction may occur. The detailed design procedures for all these cases are beyond the scope of this document and can be found elsewhere. The actual configuration of a sedimentation tank can be either rectangular or circular. Rectangular settling tanks (Fig. 6.5) are generally used when several tanks are required and there is space constraint, since they occupy less space than several circular tanks.

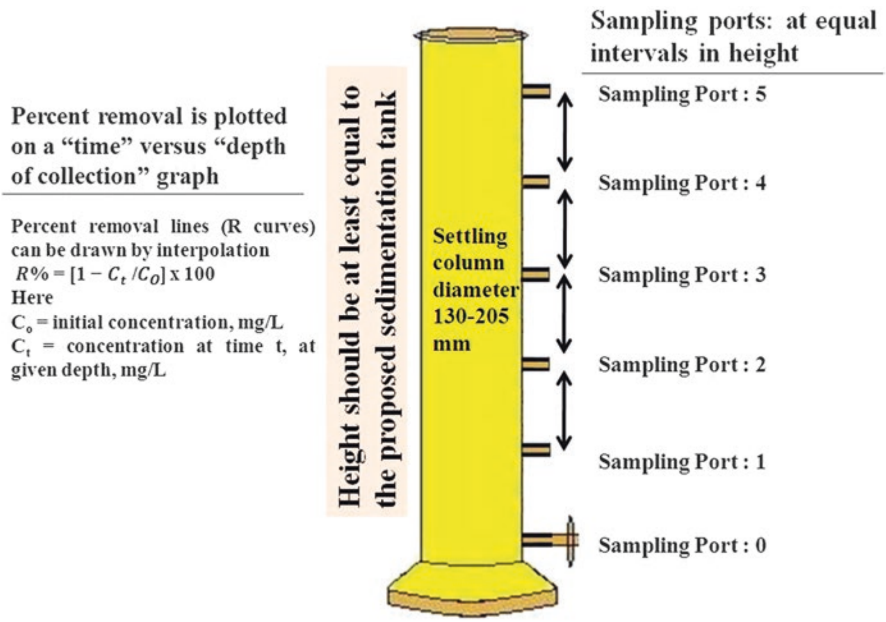


Fig. 6.3 Laboratory settling column

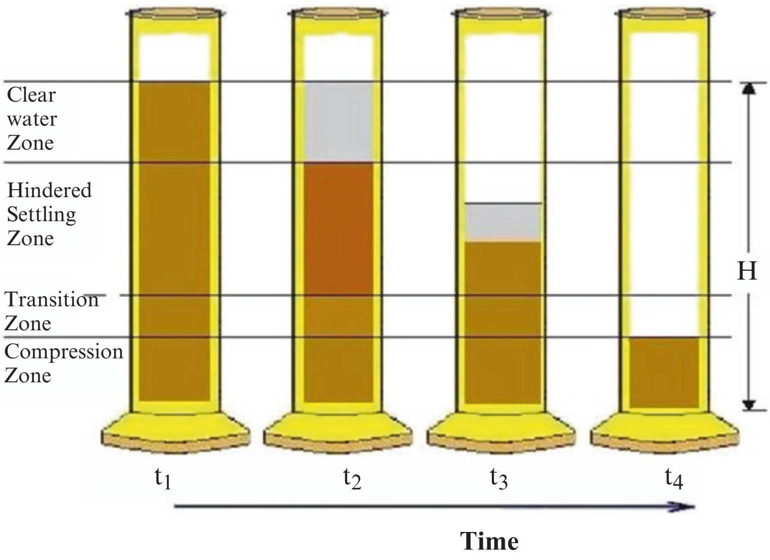


Fig. 6.4 Diagram of a zone settling process: Zone (Type III) Settling. In the bottom, a compact sludge develops in the so-called compaction zone (*4*). Between (*2*) and (*4*), a transition zone (*3*) generally exists. As time proceeds, the clarified effluent and compaction zones will increase in size, while the two intermediates will eventually disappear

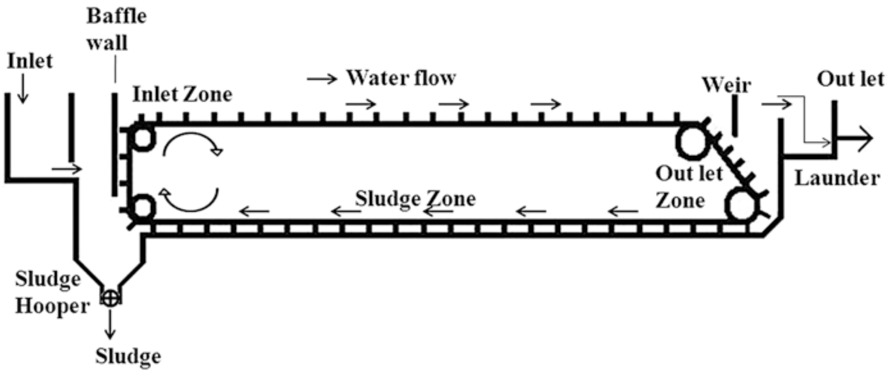


Fig. 6.5 Diagram of a rectangular clarifier

For removal of solids, a series of chain-driven scrapers are used: these span the width of the tank, are regularly spaced and move at 0.5–1 m/min. The sludge is collected in a hopper in the end of the tank, where it may be removed by screw conveyors or pumped out. Configurations exist in which the sludge is forced opposite to the flow, as shown here, but concurrent flow of the liquid and solids is also used.

Circular tanks are reported to be more effective. In these, the effluent circulates radially, the water being introduced at the periphery or from the centre. The solids are generally removed from near the centre, for which a slope of 10 % is required in the bottom of the tank. The sludge is forced to the outlet by two or four arms provided with scrapers which span the radius of the tank. For both types of flow, a means of distributing the flow in all directions is provided: for centre feed tanks there is a circular well, while for the rim-fed tanks a baffle is usually installed and the effluent enters tangentially. An even distribution of inlet and outlet flows is important to avoid short-circuiting in the tank that would reduce the separation efficiency.

A critical factor for selection of tank size is the so-called surface-loading rate, generally expressed as volume of wastewater per unit time and unit area of settler (m^3/m^2d). This loading rate depends on the characteristics of the effluent and the solids content and can be determined from the settling tests described above. The retention time in the settlers is generally in the order of 1–2 h, but the capacity of the tanks must be determined taking into account the peak flow rates so that good separation is also obtained in these cases.

In cases of small or elementary settling basins, the sludges can be removed using an arrangement of perforated piping placed in the bottom of the settling tank. The pipes must be regularly spaced, they must be of a diameter wide enough to be cleaned easily in case of clogging, and the flow velocities should also be high enough to prevent sedimentation. These last two requisites are somewhat contradictory, and a compromise is usually reached, using pipes of 5 cm in diameter, perforated with holes of 1–1.5 cm in diameter, 1 m apart. Flow in individual pipes may be regulated by valves. This configuration is best used after screening and is also found in biological treatment tanks for sludge removal. An alternative to the above configurations for settling tanks is that of the inclined tube separators. These separators consist of tubes (although there are alternate designs that use plates close to each other) which are tilted.

The concept is that, when a settling particle reaches the wall of the tube or the lower plate, it coalesces with another particle to give one of larger mass and higher settling rate.

The media are usually inclined at 45–60°. They are also commonly used to upgrade existing settling tanks since they have a higher separation rate.

6.6.2.4 Floatation

Flotation is an operation that removes not only oil and grease but also suspended solids. The most common procedure is that of dissolved air floatation (DAF), in which the waste stream is first pressurised with air in a closed tank. After passing through a pressure-reduction valve, the wastewater enters the floatation tank where, due to the sudden reduction in pressure, minute air bubbles in the order of 50–100 μm in diameter are formed. As the bubbles rise to the surface, the suspended solids and oil or grease particles adhere to them and are carried upwards. It is common practice to use chemicals to enhance floatation performance. As with coagulants (discussed later), these aids should preferably be innocuous, since these recovered solids are frequently used in animal feed formulations.

One alternate design involves the recycling of part (10–30 %) of the treated water. All systems contain a mechanism for removing the solids that may settle to the bottom of the flotation tanks, usually by a helical conveyor placed in the conical bottom. The main advantage claimed by DAF systems is the faster rate at which very small or light suspended solids can be removed in comparison with settling.

In one case, oil removal was reported to be 90 %. In tuna-processing wastewaters, the DAF removed 80 % of oil and grease and 74.8 % of suspended solids in one case and 64.3 % of oil and grease and 48.2 % of suspended solids in another case.

Another floatation system exists in which air is not dissolved but forced through the wastewater by surface aerators. This system generates air bubbles of larger sizes than DAF systems, and no report exists about its application to fishery wastewaters.

Prior to the design or selection of a DAF system, it is advisable to carry out laboratory experiments to evaluate its applicability and critical operating factors such as the air-to-solid ratio, the effectiveness of flocculants and the proper pH. This can be conveniently done in laboratory units. In these devices, water with or without chemicals and pH adjustment is introduced, and the pressure is increased to the desired value. After mixing to saturate the liquid with air, pressure is released and the liquid flows to a graduated cylinder where time is allowed for separation. The detailed procedures for conducting the evaluations are available elsewhere.

6.6.3 Secondary Treatment

The main purpose of the primary sedimentation stage is to produce both a generally homogeneous liquid capable of being treated biologically and a sludge that can be separately treated or processed. The secondary treatment process aims to reduce the BOD exerted by reducing organic matter. This is mediated, primarily, by a mixed population of heterotrophic bacteria that utilise the organic constituent for energy and growth.

Secondary treatment includes biological treatment: aerobic processes, anaerobic processes and specialised (Table 6.3). The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids.

6.6.3.1 Aerobic Processes

In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolise the organic matter in the wastewater, thereby producing more microorganisms and inorganic end products (principally CO_2, NH_3 and H_2O). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolise the organic matter.

Common high-rate processes include the activated sludge processes, trickling filters or biofilters, rotating biological contactors (RBC), fluidised bed reactor,

Table 6.3 Flow chart of waste water treatment systems

- Aerobic
  - Fixed Film
    1. Filter Beds.
    2. RBC
    3. FBR
    4. IFBBR
    5. Oxidation Ponds
    6. Oxidation Ditches
  - Suspended growth
    - Activated Sludge
      - Extended Aeration Sludge, Waste water Mixing and Aeration in separate Units
      - Contact Stabilization Sludge, waste-water Mixing and Aeration in single Unit.
      - Advanced Activated Sludge (High Purity O_2 Used)
        - Open system
          1. Vitox
          2. Megox
          3. Primox
          4. Marox
        - Closed system
          1. Unox
          2. Simplex
          3. Oases.
          4. F^3O
- Anaerobic
  - Low Rate Systems
    1. Batch
    2. Plug flow
    3. CSTR
  - High Rate Systems
    1. Anaerobic filters
    2. Contact Digestion
    3. UASB
    4. Anaerobic FBR
- Special designs
  1. Membrane Reactors
  2. SBR
  3. Hybrid System UASB/AF

IFBBR, oxidation pond, oxidation ditches, rotating drums and discs. A combination of two of these processes in series (e.g. biofilter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources.

Secondary treatment is designed to substantially degrade the biological content of the sewage such as those derived from human waste, food waste, soaps and detergent. It is normally done through aerobic processes, so elements needed include availability of microorganisms, oxygen, contact between these microorganisms and the organic material and finally, favourable environmental conditions. These requisites can be satisfied by several approaches, being the most commonly used activated sludge, trickling filters and oxidation ponds. Lastly, the rotating biological contactor is a process that does not fit into any of the previous categories, but employs principles common to trickling filters and activated sludge.

A large number of biological unit operations are available to achieve the aerobic oxidation of BOD. All operations can be classified on the basis of their microbial population, into either fixed-film or dispersed growth processes. Fixed-film reactors have biofilms attached to a fixed surface where organic compounds are adsorbed into the biofilm and aerobically degraded. In suspended (e.g. activated sludge) growth reactors, the microorganisms mix freely with the wastewater and are kept in suspension by mechanical agitation or mixing by air diffusers.

Several investigators have pointed out that biological oxidation systems can remove over 90 % of pathogenic bacteria from sewage; however, the removal of viruses is much more varied. The major mechanism of viral removal is thought to be adsorption. In suspended growth reactors, the intimate mixing of solid flocs and sewage gives 90 % removal, while the smaller surface areas of biological adsorption sites in film reactors give varied reductions.

6.6.3.1.1 Biological Filters: Fixed-Film Systems

Fixed-film systems use a medium to retain and grow microorganisms. Fixed-film systems (FFS) are biological treatment processes that employ a medium such as rock, plastic, wood or other natural or synthetic solid material that will support biomass on its surface and within its porous structure.

At least two types of fixed-film systems may be considered – those in which the medium is held in place and is stationary relative to fluid flow (trickling filter) and those in which the medium is in motion relative to the wastewater (e.g. rotating biological disc).

Fixed Bed: Trickling Filters

Trickling filter systems are typically constructed as beds of media through which wastewater flows. Oxygen is normally provided by natural or forced ventilation. Flow distributors or sprayers distribute the wastewater evenly onto the surface of the medium. As the wastewater moves by gravity through the medium, soluble and colloidal organic matter is metabolised by the biofilm that forms on the medium. Excess biomass sloughs from the medium and is carried with the treated wastewater to the clarifier, where the solids settle and separate from the treated effluent. At this point the treated wastewater may be discharged or recycled back to the filter medium for further treatment.

The trickling filter consists of a bed of coarse material, such as stones, slats, rocks, gravel, slag, sphagnum, peat moss, plastic materials or another highly permeable media, over which wastewater is applied. As the wastewater trickles through the bed, a microbial growth establishes itself on the surface of the stone or packing in a fixed film. The wastewater passes over the stationary microbial population, providing contact between the microorganism and the organic contaminants, allowing degradation processes.

The trickling filter works through the formation of a biofilm on the media which degrades the organic compounds and ammonium in the wastewater. The wastewater is fed to the top of the trickling filter using a pump and collected at the bottom in a sump. Oxygen is made accessible to the bacteria through the use of a fan or solely through natural convection. As the biofilm continues to grow, an anaerobic section of the filter is formed, since the oxygen cannot diffuse through the thickening biofilm well. Parts of the biofilm slough off as it grows in size, and this slough is clarified or settled out after being collected at the sump. Trickling filters are advantageous for small to medium communities that do not have a lot of land to dedicate to wastewater treatment.

Rotating Biological Contactors (RBC)

These mechanical secondary treatment systems employ rotating discs that move within the wastewater are referred to as a rotating biological contactor (RBC). This is a fixed-film biological treatment process that is robust and capable of withstanding surges in organic load. Developed in the late 1960s, the RBC employs a plastic medium configured as discs and mounted on a horizontal shaft. Rotating biological contactors (RBCs) consist of closely spaced, slowly rotating, plastic discs on a shaft which is moved by a motor.

The shafts are rotated slowly (1–2 rpm) by mechanical or compressed air drive. For a typical aerobic RBC, approximately 40 % of the medium is immersed in the wastewater. Anoxic or anaerobic RBCs (far less common) are fully immersed in the wastewater. Wastewater flows through the medium by simple displacement and gravity. Biomass continuously sloughs from the discs, and some suspended biomass develops within the wastewater channels through which the discs rotate, making the addition of a secondary clarifier necessary. The rotation of the discs exposes the attached biomass to atmospheric air and wastewater. Oxygen is supplied by natural surface transfer to the biomass. The biofilm size is controlled by the shear forces of rotation. This is advantageous, because it prevents overgrowth of the biofilm which could limit oxygen to the aerobic bacteria. Sheared off excess biomass is removed through a final settler or clarifier where the microorganisms in suspension settle as sludge.

Some oxygenation of the wastewater is also created by turbulence at the disc-water interface. The use of exposed and submerged stages in multiple tanks to create aerobic and anoxic conditions may be employed where nitrogen removal is required.

RBCs are simpler to operate than activated sludge systems and have longer contact times between the bacteria and the pollutants than trickling filters. The start-up cost for RBCs is high, but the maintenance and energy costs are low.

Fluidised Bed Reactor (FBR)

A fluidised bed reactor (FBR) is a type of reactor device that can be used to carry out a variety of multiphase chemical reactions. In this type of reactor (Fig. 6.6), a fluid (gas or liquid) is passed through a granular solid material (usually a catalyst possibly shaped as tiny spheres) at high enough velocities to suspend the solid and cause it to behave as though it were a fluid. The solid substrate (the catalytic material upon which chemical species react) material in the fluidised bed reactor is typically supported by a porous plate, known as a distributor. The fluid is then forced through the distributor up through the solid material. At lower fluid velocities, the solids remain in place as the fluid passes through the voids in the material. This is known as a packed reactor. As the fluid velocity is increased, the reactor reaches a stage where the force of the fluid on the solids is enough to balance the weight of the solid material. This stage is known as incipient fluidisation and occurs at this minimum fluidisation velocity. Once this minimum velocity is surpassed, the contents of the reactor bed begin to expand and swirl around much like an agitated tank or boiling pot of water. The reactor is now a fluidised bed. Depending on the operating conditions and properties of solid phase, various flow regimes can be observed in this reactor. In the 1930s, the fluidised bed reactor (FBR) appeared as a new alternative for biological treatment of wastewaters. In this type of reactor, a high

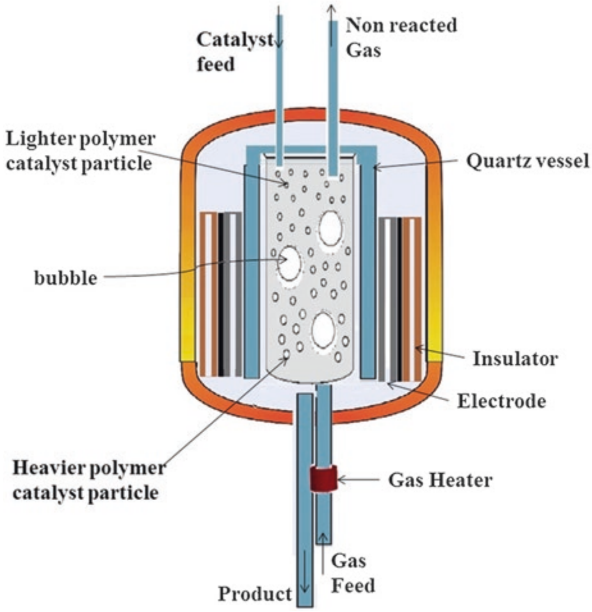


Fig. 6.6 Basic diagram of a fluidised bed reactor

concentration of biomass is maintained inside because microorganisms are attached to support particles.

The main advantages of using FBR are the lower hydraulic retention time (HRT) and the small size of equipment. In FBRs, it is possible to achieve a high concentration of biomass depending on the operational conditions used in the process and the type of support used to immobilise the microorganisms, which are found within a complex structure of cells and their extracellular products, referred to as a biofilm. The cell volume inside the biofilm is only a small part of its total volume. Dense particles were traditionally used in FBRs as a support for the biofilm. Entrainment of support particles from the reactor was a problem that appeared as the biofilm grew, decreasing particle density.

FBRs have many advantages over other processes.

1. High specific area is available to microorganisms.
2. Minimum problems related to channelling, plugging and gas hold-up.
3. Biofilm thickness is controlled by particle motion and liquid upflow velocities minimising the diffusion problems through biofilms.
4. Uniform liquid flow distribution.
5. Small installation is required.

Inverse Fluidised Bed Biofilm Reactors (IFBBR)

In inverse fluidised bed biofilm reactors (IFBBR) containing low-density particles, fluidisation can be conducted either by an upward co-current flow of gas and liquid through a bed (Fig. 6.7) (Bandaru et al. 2007) or by a downward flow of liquid and

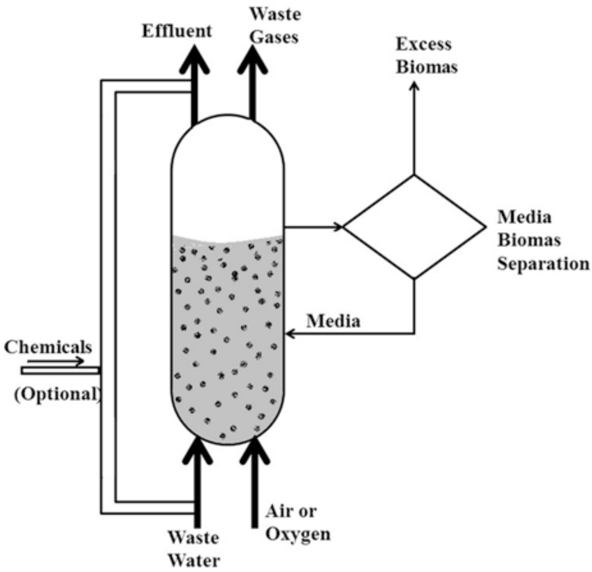


Fig. 6.7 Inverse fluidised bed biofilm reactor scheme

countercurrent upward flow of gas. In the former, fluidisation is achieved by an upward flow of gas whereby the gas bubbles make the bed expanding downwards into the less dense mixture of gas and liquid. In the latter, the bed is fluidised by a downward flow of a liquid counter to the net buoyancy force of the particles. At a small flow of the liquid, not sufficient to counter to the net buoyancy force, fluidisation can be achieved by an adequate upward flow of the gas. Fluidisation where fluidised bed expands downwards is termed as inverse fluidisation.

Three advantages of IFBBR are:

1. Effective and simple control of biofilm thickness
2. Large specific support surface area
3. Fast biofilm formation

Oxidation Ponds

The term oxidation ponds has been used lately as a collective name for all kinds of treatment ponds. Essentially, all work on the same principle: the use of ponds and basins designed taking wastewater flow conditions in consideration so that wastewater remains for sufficient time in the basin to allow degradation of organic matter take place. There are five basic types, namely, aerobic, anaerobic, facultative, maturation or tertiary ponds and aerated lagoons.

Oxidation Ditches

It is particular type of extended aeration process, where an aeration tank is constructed in the shape of a ditch (oval shape). An aeration tank consists of a ring-shaped channel 1.0–1.5 m deep and of suitable width forming a trapezoidal or rectangular channel cross section. An aeration rotor, consisting of Kessener brush, is placed across the ditch to provide aeration and wastewater circulation at velocity of about 0.3–0.6 m/s. The oxidation ditch can be operated as intermittent with fill and draw cycles consisting of (a) closing inlet valve and aerating the wastewater for duration equal to design detention time, (b) stopping aeration and circulation device and allowing the sludge to settle down in the ditch itself and (c) opening the inlet and outlet valve allowing the incoming wastewater to displace the clarified effluent. In case of continuous operation, called as Carrousel process, it is operated as a flow-through system where wastewater is continuously admitted. The vertically mounted mechanical aerators are used to provide oxygen supply and at the same time to provide sufficient horizontal velocity for not allowing the cells to settle at the bottom of the ditch. Separate sedimentation tank is used to settle the sludge, and the settled sludge is recirculated to maintain necessary MLVSS in the oxidation ditch. The excess sludge generation in oxidation ditch is less than the conventional ASP and can be directly applied to the sand-bed for drying.

6.6.3.1.2 Suspended Growth

In a suspended growth system, the waste flows around and through free-floating microorganisms, gathering into biological flocs that settle out of the wastewater. The settled flocs retain the microorganisms, meaning they can be recycled for further treatment.

Activated Sludge Process (ASP)

In the activated sludge process, atmospheric air or pure oxygen is bubbled through primary wastewater combined with organisms (a suspension of the wastewater and microorganisms in the mixed liquor) in an aeration tank to develop a biological floc which reduces the organic content of the wastewater. The contents of the aeration tank are mixed vigorously by aeration devices which also supply oxygen to the biological suspension. Aeration devices commonly used include submerged diffusers that release compressed air and mechanical surface aerators that introduce air by agitating the liquid surface. Hydraulic retention time in the aeration tanks usually ranges from 3 to 8 h but can be higher with high BOD_5 wastewaters. Following the aeration step, the microorganisms are separated from the liquid by sedimentation, and the clarified liquid is secondary effluent. A portion of the biological sludge is recycled to the aeration basin to maintain a high mixed liquor suspended solids (MLSS) level. The remainder is removed from the process and sent to sludge processing to maintain a relatively constant concentration of microorganisms in the system. Once the wastewater has received sufficient treatment, it is discharged into settling tanks, and the treated supernatant is run off to undergo further treatment before discharge. To achieve specific effluent goals for BOD, nitrogen and phosphorus, different adaptations and modifications have been made to the basic activated sludge design.

(a) Extended aeration sludge

The extended aeration process is one of the modifications of the ASP. It is a complete mix system and provides biological treatment for the removal of biodegradable organic wastes under aerobic conditions. Air may be supplied by mechanical or diffused aeration to provide the oxygen required to sustain the aerobic biological process. Mixing must be provided by aeration to maintain the microbial organisms in contact with the dissolved organics. Since a complete stabilisation occurred in the aeration tank, there is no need for a separate sludge digester. Further primary settling tank is also omitted, and settleable organic solids are also allowed to settle in the aeration tank due to long detention time in the aeration tank.

(b) Contact stabilisation sludge

It is developed to take advantage of the absorptive properties of activated sludge (Fig. 6.8). The BOD removal in ASP occurs in two phases: in the first phase absorption and second phase of oxidation. The absorptive phase requires 30–40 min, and during this phase most of the colloidal, finely divided, suspended solids and dissolved organic matter get absorbed on the activated sludge. Oxidation of organic matter then occurs. In contact stabilisation, these two phases are separated out and they occur in two separate tanks.

The settled wastewater is mixed with re-aerated activated sludge and aerated in the contact tank for 30–90 min. During this period the organic matter is absorbed on the sludge flocs. The sludge with absorbed organic matter is separated from the wastewater in the SST. A portion of the sludge is wasted to maintain requisite MLVSS concentration in the aeration tank. The return sludge is aerated before sending it to aeration tank for 3–6 h in sludge aeration tank, where the absorbed organic matter is oxidised to produce energy and new cells. Contact stabilisation is effective for treatment of sewage; however, its use to the industrial wastewater may be limited when the organic matter present in the wastewater is mostly in the dissolved form. Existing treatment plant can be upgraded by changing the piping and providing partition in the aeration tank. This modification will enhance the capacity of the existing plant. This is effective for sewage treatment because of the presence of organic matter in colloidal form in the sewage. Contact stabilisation may not be that effective for the treatment of wastewater when the organic matter is present only in soluble form.

(c) Advanced activated sludge

Advanced sludge treatment (AST) processes have been developed to improve sludge dewatering and facilitate the ultimate disposal. These processes include

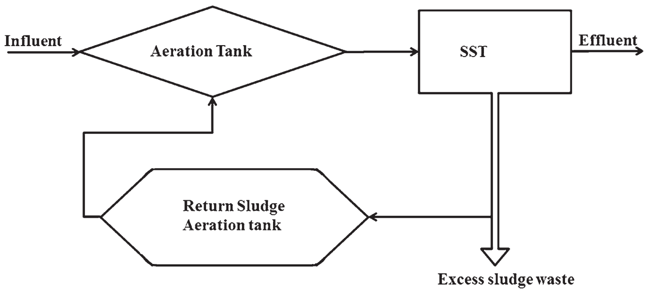


Fig. 6.8 Contact stabilisation activated sludge process

thermal hydrolysis (neutral, acid, alkaline) or chemical oxidation by H_2O_2, O_3, O_2, etc.. Peroxidation (H_2O_2) can thicken the sludge (5–6 % dry solids) from a municipal sewage treatment plant. Effective dewatering requires the attack of the microorganisms. The vast majority of these microorganisms live in aggregates such as films, flocs and sludges.

Advance activated sludge processes are classified into two types of system: ‘open’ and ‘closed’. The closed system was firstly developed by the Union Carbide Corporation, USA, while the ‘open’ system was developed at the British Oxygen Company, UK. Further modifications were developed elsewhere.

In the closed system, oxygen is dispersed into covered tanks, the content of which are mixed by Verticle spindle vane impellers. In open system, oxygen is injected into the throat of a Venturi tube in a side stream through which mixed liquor is continuously recycled.

Closed Systems

UNOX

The UNOX system has been developed to improve upon the conventional activated sludge process. The use of enriched oxygen in a simple and economical multistage gas-liquid contacting device allows oxygen to be transferred to wastewater at increased rates with significant decreases in power requirements over those required when using air as the oxygen supply media. The elimination of the mass transfer restriction allows operation at solid levels of 4500–7000 mg/l while maintaining a dissolved oxygen level of 8–10 mg/l in the mixed liquor. Retention times for the process can be correspondingly decreased to 1–2 h. A highly flocculant sludge is obtained which has excellent settling and dewatering characteristics and is produced in less quantities than normally produced by a conventional air activated sludge process. The process has been demonstrated in a 2.5 mgd activated sludge plant at Batavia, New York. During the Federal Water Quality Administration (FWQA) contract, the UNOX process was able to demonstrate consistent BOD and suspended solid removals in excess of 90 %. A number of pilot plant programmes in municipal waste applications continue to verify and confirm the excellent treatment effectiveness and decreased power requirements achieved with the system.

OASES

The OASES is an oxygen activated sludge process for secondary treatment of wastewater. The system includes parallel trains consisting of a number of covered, separated stages. Influent wastewater, recycled activated sludge (RAS) and high purity oxygen are introduced to the first stage of each train of operation and flow through succeeding stages. The mixed liquor is subsequently sent to additional processes for further biological treatment and/or clarification. The process produces a good settling sludge and can be operated at high organic loading rates.

This is developed by Air Products and Chemicals Inc., USA. Many features are similar to UNOX system. It has surface aerators in enclosed aeration chamber as in UNOX but also has additional bottom turbines for enhanced mixing. Gas and liquid flow is concurrent through a series of contacting stages, and oxygen supply is controlled by a pressure demand system. As the oxygen is consumed, the head space pressure drops and more oxygen is admitted through the pressure control valves.

Forced Free Fall (F_3O)

This has been developed by Airco Inc. in the USA. In this process, mixed liquor falls through an enclosed oxygen-rich atmosphere contained in a precast module. The oxygenation module is completely submerged in the aeration basin, from which mixed liquor is pumped into the module. After oxygenation, the mixed liquor is returned to the aeration basin, and the dissolved oxygen concentration in the mixed liquor is used to control the oxygen supply rate and height of liquid fall.

SIMPLEX

The simplex system has been developed at Bury Sewage Works by Joshua Bolton. This is a low-cost modified conventional air activated sludge system. It has a plastic cover inside the basin. O_2 is introduced into specially installed fine double diffusers. O_2 in the head space is recirculated throughout the existing coarse bubble sparger and partially purged using a gas blower.

Open Systems

MAROX

This has been developed by the FMC Corporation in the USA. Here, rotating diffusers are used, and 92–95 % oxygen utilisation occurs, making it two to six times more efficient than the conventional process.

VITOX

This has been developed by the BOC Ltd., and VITOX 1 and VITOX 2 are the two systems used. In VITOX 1, liquid is pumped at a pressure and oxygen is injected into it. O_2 is trapped in the form of fine bubbles. This gas-liquid flow is then discharged into a mixed liquor oxygenation tank through an expansion nozzle. High velocity discharge and subsequent turbulence in the tank give very fine bubbles, and oxygen utilisation achieved is 95 %. The VITOX 2 system has a bell diffuser. Here, O_2 is injected with the liquid stream. This then falls at very low velocity into the vessel, and only small bubbles fall while larger bubbles are retained in contactor vessels.

Oxygen transfer can be achieved by using air or pure oxygen. However, air contains only ~21 % oxygen in it. So when wastewater treatment demands vary and performance standards become stringent, pure oxygen-based delivery system can be utilised to significantly enhance the process.

Vitox systems are extremely efficient and powerful dissolution systems for upgrading existing plants and for purpose-built systems. These systems are ideal solutions for permanent or intermittent effluent overloading or oxygenation shortfall.

MEGOX
This has also been developed by BOC Ltd. The wastewater is mixed with sludge recycle stream, injected with oxygen and then passed into the central reaction zone of a treatment tank. No additional agitation is required, and sludge settles with the aid of a slow speed rotating consolidator. The treated liquor goes to a clarifying zone and then discharged. The O_2 injection is controlled by a sensor in the sludge recycle system. The process is particularly suitable for nutrient-rich wastewater as in food-processing industries, and up to 86 % COD is removed from the wastewater feed with 3800–4400 g/m^3 COD and 2000 g/m^3 suspended solids.

PRIMOX
This is used as a part of sewage system. Anaerobic conditions and the associated problem of corrosive H_2S production are avoided by the application of this process.

6.6.3.2 Anaerobic Process

Anaerobic treatment (Fig. 6.9) is a biological process carried out in the absence of O_2 for the stabilisation of organic materials by conversion to CH_4 and inorganic end products such as CO_2 and NH_3.

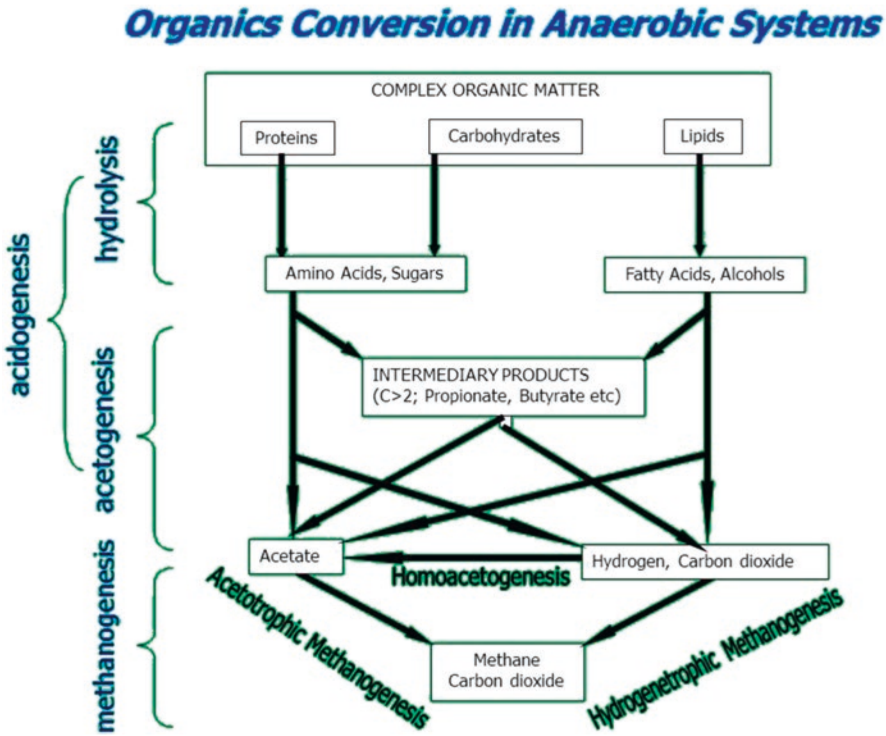


Fig. 6.9 General scheme for organic conversion in anaerobic system S_o and Q can be measured easily and known upfront VOLR can be selected

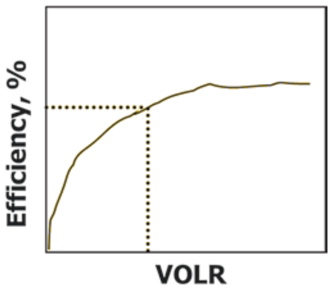
$$\text{Organic materials} + \text{Nutrients} \xrightarrow[\text{Anaerobic microbes}]{} CH_4 + CO_2 + NH_3 + \text{Biomass}$$

Anaerobic treatment is mainly used for reducing mass of high solid wastes, e.g. human waste, animal manure, agricultural waste and sludge. The treatment is divided in 'low-rate' systems, in which long hydraulic retention times are applied, and 'high-rate' systems, in which hydraulic retention time is relatively short.

Design based on volumetric organic loading rate (VOLR):

$$\text{VOLR} = \frac{S_o \cdot Q}{V}$$

VOLR: volumetric organic loading rate (kg COD/m^3-day)
So: wastewater biodegradable COD (mg/L)
Q: wastewater flow rate (m^3/day)
V: bioreactor volume (m^3)



Conduct a pilot scale studies.
Find out removal efficiency at different VOLRs.
Select VOLR based on desired efficiency.

Design based on hydraulic loading rate:

$$V = \theta a \cdot Q$$

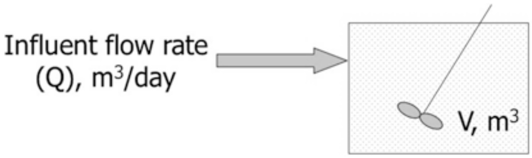
$$A = \frac{\theta_a \cdot Q}{H}$$

H = reactor height (m)
θ_a = allowable hydraulic retention time (hr)
Q = wastewater flow rate (m^3/h)
A = surface area of the reactor (m^2)

Permissible superficial velocity (*Va*)

$$V_a = H/\theta \text{ For dilute wastewater with COD} < 1000\text{mg/L}$$

Low-rate systems are used mainly for waste streams such as slurries and solid waste, which require a long time for sufficient anaerobic degradation. High-rate systems are used mainly for wastewater. The retention time of sludge in a low-rate system (solid retention time; SRT) is equal to the hydraulic retention time (HRT). In high-rate systems, however, the sludge retention time should be much higher than the hydraulic retention time.



$$\text{HRT, days} = \frac{\text{Volume}}{\text{Flow rate}} = \frac{V\ (m^3)}{Q\ (m^3/\text{day})}\ \text{day}$$

For a given SRT (HRT), the size of reactor can be easily determined since flow rate (Q) is known to us

$$\text{Digester volume, } V\ (m^3) = \text{Flow rate } (Q) \times \text{SRT } (\theta_C)$$

Examples of low-rate systems are batch, accumulation, plug flow and continuous stirred tank reactor (CSTR) systems. Examples of high-rate systems are contact process, anaerobic filter, fluidised bed and upflow anaerobic sludge bed (UASB)/expanded granular sludge bed (EGSB).

6.6.3.2.1 Low-Rate Systems

Batch System

This is a process by which a reactor is filled with feedstock in one sequence, then processed and finally emptied in one instance.

Some of the first dry digesters were envisioned as modified landfills. In batch-fed digesters, the reactors are filled with a feedstock, closed and left for a period of time (i.e. the retention time) and then opened again and emptied (Khalid et al. 2011). Vandevivere et al. (2003) state that batch systems represent the lowest technology of all systems and are also the cheapest. Due to their simple design and lower investments costs, batch systems are recommended for application in developing countries. However, experience shows that these reactors have some serious limitations. Each batch, once closed, undergoes the whole start-up phase of the methanogenic process. This implies that there will be high fluctuations in gas production until the system operates in a stable way. Variations are also observed in gas quality. The height of the reactor is limited to ensure good infiltration of the percolate. Furthermore gastight sealing of inlet/outlet can be challenging especially as the doors are regularly closed and opened after each batch sequence. This may result in biogas losses and the risk of explosion when emptying a residual methane in the reactor mixes with air (Vandevivere et al. 2003).

Plug Flow Reactor

Plug flow digesters use slurries, e.g. almost undiluted manure and have a total suspended solid concentration of 10–12 % TS. The basic digester design is a long trough (Fig. 6.10), often built below ground level with a gastight but expandable cover. At low TS concentration problems with floating and settling layers can appear. This problem can be solved using vertical mixing inside the pipe. In this particular process, anaerobic stages such as hydrolysis and methanogenesis are separated over the length of the pipe. At first, hydrolysis mainly occurs, whereas later in the process methanogenesis takes place at full velocity.

Using this system, the SRT is equal to the HRT. These systems are frequently used to treat slurries with a high fraction of suspended solids, as the hydrolysis of particulate matter is rate limiting; hence, only low loading rates can be applied.

Continuous Stirred Tank Reactor (CSTR)

The most common form of low solid reactor is the continuous stirred tank reactor (CSTR).

Feed is introduced into the reactor, which is stirred continuously to ensure complete mixing of the reactor contents. At the same time an equal quantity of effluent is removed from the reactor.

Retention time within the reactor can be varied according to the nature of the feedstock and process temperature applied, which is typically in the range of 2–4 weeks. Such systems have a low operating expenditure.

The CSTR is generally used for treatment of slurries with a TS percentage of approximately 2–10 %. The influent concentration range applicable for CSTRs is determined by:

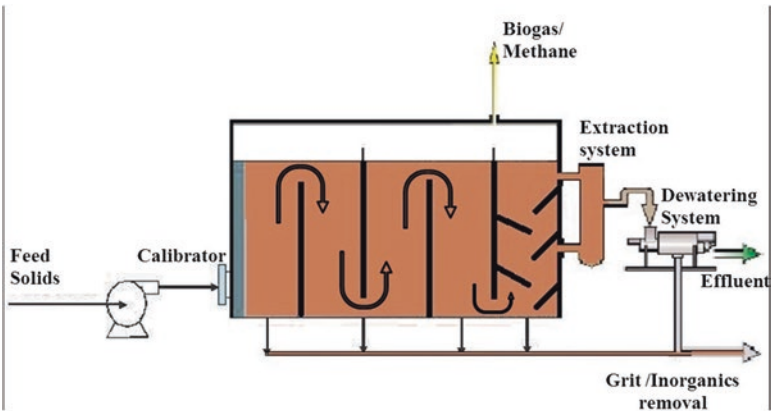


Fig. 6.10 Schematic diagram of a plug flow digester

- Gas yield in relation to the energy requirement for heating
- Possibility of mixing the reactor content

CSTR systems are applied in practice for treating animal manure, sewage sludge, household waste, agricultural wastes, faeces, urine and kitchen waste or mixtures of these substrates. Mixing creates a homogeneous substrate, preventing stratification and formation of a surface crust, and ensures solids remain in suspension. Bacteria, substrates and liquid consequently have an equal retention time resulting in SRT which is equal to HRT.

Digester volume ranges from around 100 m^3 to several thousand cubic metres, often with retention times of 10–20 days, resulting in daily capacities of 6–400 m^3. Examples of CSTR digesters with different mixing and heating systems are shown in Fig. 6.11.

6.6.3.2.2 High-Rate Systems: Anaerobic Filters

An anaerobic filter is a fixed-bed biological reactor with one or more filtration chambers in series (Fig. 6.12). As wastewater flows through the filter, particles are trapped and organic matter is degraded by the active biomass that is attached to the surface of the filter material. Developed by Young and McCarty in the late 1960s to treat dilute soluble organic wastes, the filter was filled with rocks similar to the trickling filter. Wastewater was distributed across the bottom, and the flow was in the upward direction through a bed of rocks. The filter is submerged completely. Anaerobic microorganisms accumulate within voids of media (rocks or other plastic media). The media retain or hold the active biomass within the filter. Non-attached biomass within the interstices forms bigger flocs of granular shape due to rising gas bubble/liquid. Non-attached biomass contributes significantly to waste treatment. Anaerobic filters are widely used as secondary treatment in household black or grey water systems and improve the solid removal compared to septic tanks or anaerobic baffled reactors. Since anaerobic filters work by anaerobic digestion, they can be designed as anaerobic digesters to recover the produced biogas. An anaerobic filter is an attached biofilm system (fixed-bed or fixed-film reactor; see also fixed-film activated sludge) that aims at removing non-settleable and dissolved solids (Morel and Diener 2006). As septic tanks or anaerobic baffled reactors, anaerobic filters are

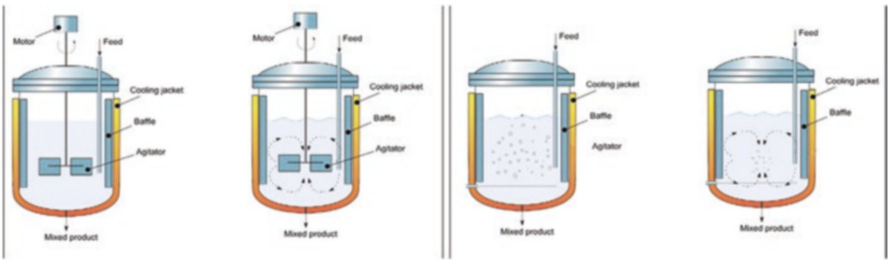


Fig. 6.11 Schematic diagram of a CSTR system, mechanically stirred (*left*) and stirred by biogas recirculation (*right*)

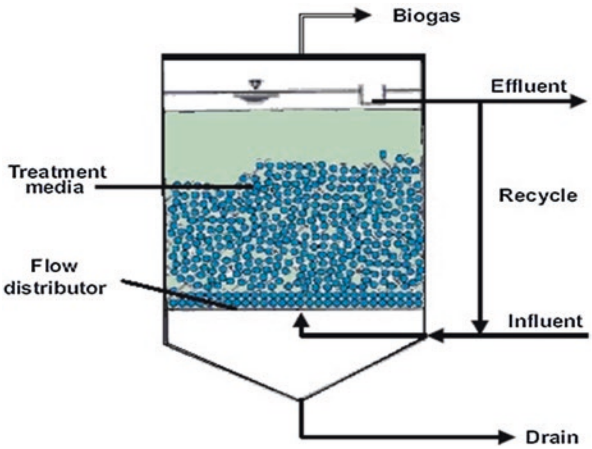


Fig. 6.12 Schematic diagram of an anaerobic filter

based on the combination of a physical treatment (settling) and a biological treatment (see also anaerobic digestion).

Contact Digestion

Anaerobic contact process (ACP) is essentially an anaerobic activated sludge process. It consists of a completely mixed reactor followed by a settling tank (Fig. 6.13). The settled biomass is recycled back to the reactor. Hence, ACP is able to maintain high concentration of biomass in the reactor and thus high solid retention time (SRT) irrespective of hydraulic retention time (HRT). A degasifier allows the removal of biogas bubbles (CO_2, CH_4) attached to a sludge which may otherwise float to the surface. ACP was initially developed for the treatment of dilute wastewater such as meat packing plant which had tendency to form settleable flocs. An ACP is suitable for the treatment of wastewater containing suspended solids which render the microorganisms to attach and form settleable flocs.

Upflow Anaerobic Sludge Blanket Reactor (USAB)

UASB was developed in 1970s by Lettinga in the Netherlands. It is essentially a suspended growth system in which proper hydraulic and organic loading rate is maintained in order to facilitate the dense biomass aggregation known as granulation. The size of granules is about 1–3 mm diameter. Since granules are bigger in size and heavier, they will settle down and be retained within the reactor. The concentration of biomass in the reactor may become as high as 50 g/L. Thus a very high SRT can be achieved even at a very low HRT of 4 h. The granules consist of hydrolytic bacteria, acidogen/acetogens and methanogens. Carbohydrate-degrading granules show layered structure with a surface layer of hydrolytic/fermentative acidogens. The mid-layer is comprised of syntrophic colonies and an interior with acetogenic methanogens (Fig. 6.14).

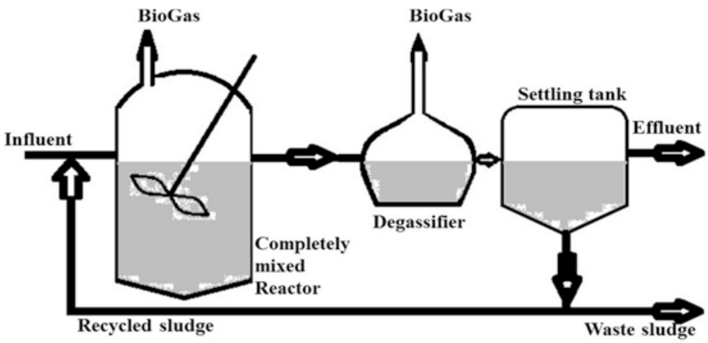


Fig. 6.13 Anaerobic contact process

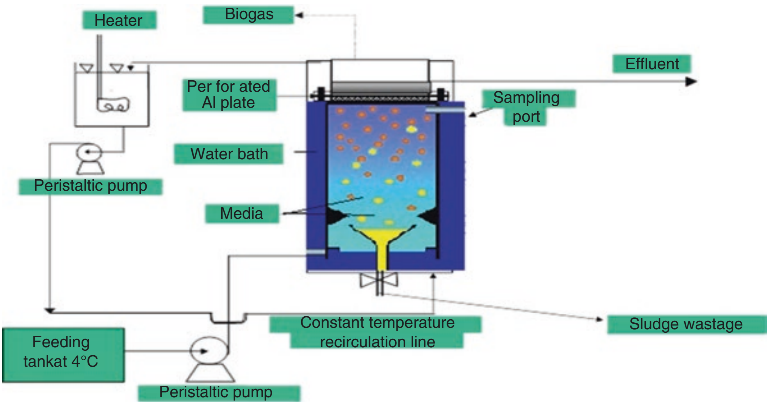


Fig. 6.14 Upflow anaerobic sludge blanket reactor

Anaerobic Fluidised Bed Reactor (FBR)

FBR is truly a fixed-film reactor as suspended biomass is washed out due to high upflow velocity. The bed expansion is 25–300 % of the settled bed volume, which requires much higher upflow velocity (10–25 m/h). The biomass gets attached on bio-carriers such as sandman, pulverised polyvinyl chloride and shredded tyre beads. The bio-carriers are supported entirely by the upflow liquid velocity and therefore able to move freely in the bed. The fluidised bed reactor is free from clogging problem short-circuiting and better substrate diffusion within the biofilm.

Expanded bed reactor (EBR) is an attached growth system with some suspended biomass that is similar to FBR.

6.6.3.3 Special Design Reactors

Membrane Reactors

Membrane bioreactors (MBR) are treatment processes (Fig. 6.15), which integrate a permselective or semipermeable membrane with a biological process. It is the combination of a membrane process like microfiltration or ultrafiltration with a

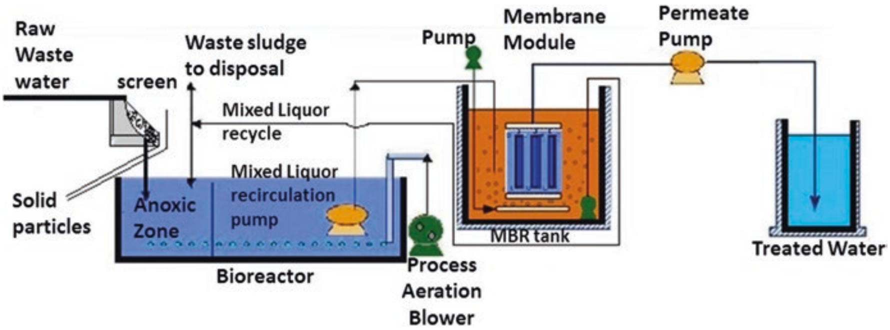


Fig. 6.15 Typical schematic for membrane bioreactor system

suspended growth bioreactor and is now widely used for municipal and industrial wastewater treatment with plant sizes up to 80,000 population equivalents. Due to it being a very technical solution, it needs expert design and skilled workers. Furthermore, it is a costly but efficient treatment possibility. With the MBR technology, it is possible to upgrade old wastewater plants.

Membrane bioreactors combine conventional biological treatment (e.g. activated sludge) processes with membrane filtration to provide an advanced level of organic and suspended solid removal. When designed accordingly, these systems can also provide an advanced level of nutrient removal. In an MBR system, the membranes are submerged in an aerated biological reactor.

The MBR process involves a suspended growth activated sludge system that utilises microporous membranes for solid/liquid separation in lieu of secondary clarifiers. This very compact arrangement produces a MF/UF quality effluent suitable for reuse applications or as a high-quality feed water source for reverse osmosis treatment. Indicative output quality of MF/UF systems includes SS <1 mg/L, turbidity <0.2 NTU and up to four log removal of virus (depending on the membrane nominal pore size). In addition, it provides a barrier to certain chlorine-resistant pathogens such as *Cryptosporidium* and *Giardia*.

The MBR process is an emerging advanced wastewater treatment technology that has been successfully applied at an ever increasing number of locations around the world. In addition to their steady increase in number, MBR installations are also increasing in terms of scale. A number of plants with a treatment capacity of around 5–10 ML/day have been in operation for several years now while the next generation (presently undergoing commissioning or under contract) have design capacities up to 45 ML/day.

Sequence Batch Reactor (SBR)

Sequence batch reactor is a special type of activated sludge process in which all the treatment takes place in the reactor tanks and clarifiers are not required. These processes treat the wastewater in batch mode, and each batch is sequenced through a series of stages.

Wastewater treatment is achieved by a timed sequence of operations which occurs in the same SBR tank, consisting of filling, reaction (aeration), settling, decanting, idling and sludge wasting (Fig. 6.16).

Secondary Clarifier the SBR tank acts as a secondary clarifier during the settling and decanting stages where the mixed liquor is allowed to settle under quiescent conditions and the overflow is discharged to the next stage of treatment.

Sludge Return System the activated sludge, following settling in the SBR tank, is mixed with the influent similar to the sludge return system, except that the feed is

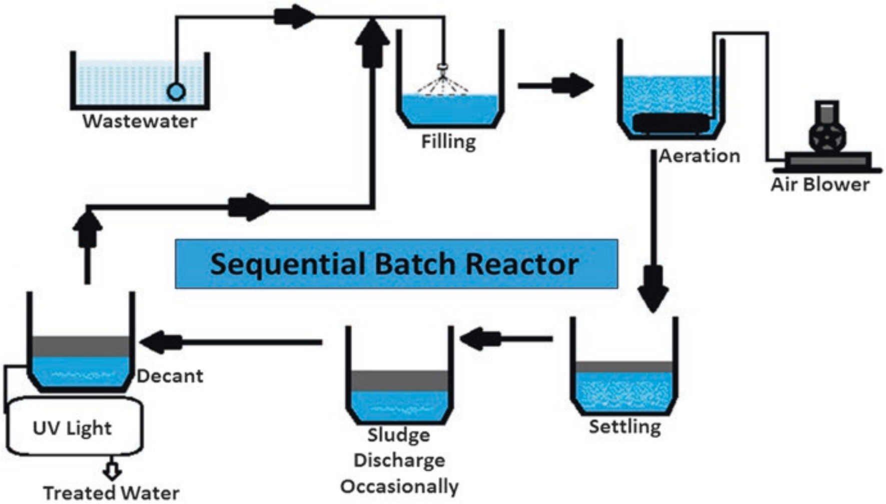


Fig. 6.16 Sequence batch reactor having various stages. ***Stage*** **1**: **Filling**. During this stage, the SBR tank is filled with the influent wastewater. In order to maintain suitable F/M (food-to-microorganism) ratios, the wastewater should be admitted into the tank in a rapid, controlled manner. This method functions similarly to a selector, which encourages the growth of certain microorganisms with better settling characteristics. ***Stage*2**: **Reaction**. This stage involves the utilisation of biochemical oxygen demand (BOD) and ammonia nitrogen, where applicable, by microorganisms. The length of the aeration period and the sludge mass determines the degree of treatment. The length of the aeration period depends on the strength of the wastewater and the degree of nitrification (conversion of the ammonia to a less toxic form of nitrate or nitrite) provided for in the treatment. ***Stage*** **3**: **Settling**. During this stage, aeration is stopped and the sludge settles leaving clear, treated effluent above the sludge blanket. Duration for settling varies from 45 to 60 min depending on the number of cycles per day. ***Stage*** **4**: **Decanting**. At this stage of the process, effluent is removed from the tank through the decanter, without disturbing the settled sludge. ***Stage*** **5**: **Idling**. The SBR tank waits idle until it is time to commence a new cycle with the filling stage. ***Stage*** **6**: **Sludge wasting**. Excess activated sludge is wasted periodically during the SBR operation. As with any activated sludge treatment process, sludge wasting is the main control of the effluent quality and microorganism population size. This is how the operator exerts control over the effluent quality by adjusting the mixed liquor suspended solids (MLSS) concentration and the mean cell residence time (MCRT).

transferred to the sludge rather than the sludge being transferred to the front end of the plant.

Hybrid System

Hybrid system may be any combination of two types of reactor. Hybrid system incorporates both granular sludge blanket (bottom) and anaerobic filter (top) (Fig. 6.17). Such an approach prevents washout of biomass from the reactor. Additional treatment takes place at the top bed due to the retention of sludge granules that escape from the bottom sludge bed. A UASB reactor facing a chronic sludge wash-out problem can be retrofitted using this approach.

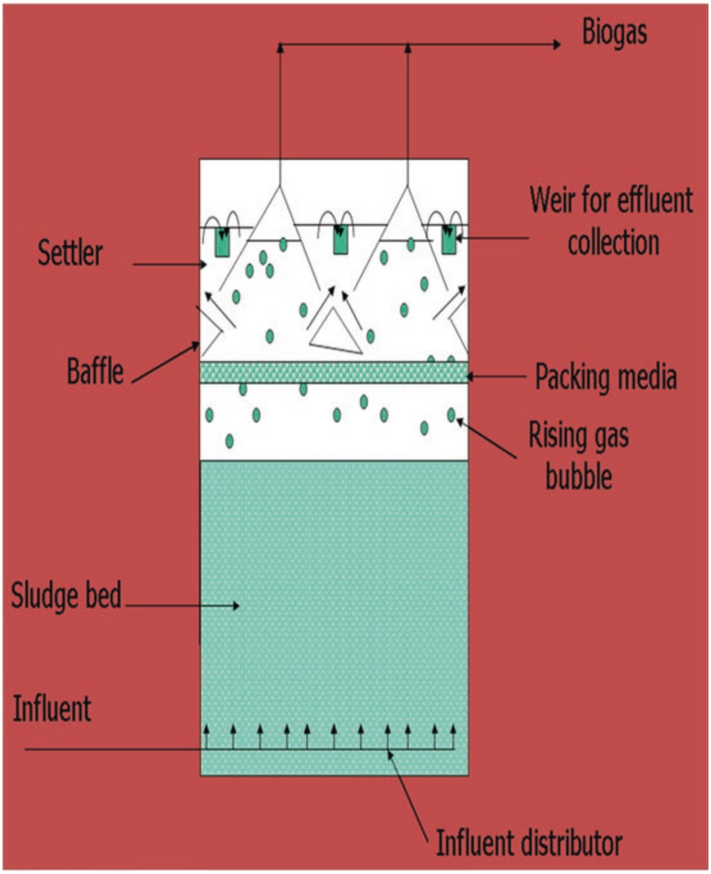


Fig. 6.17 Hybrid system having UASB (*bottom*) and AF (*top*)

6.6.4 Tertiary Treatment

Tertiary wastewater treatment is employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed such as nitrogen, phosphorus and heavy metals (Fig. 6.18). Each tertiary treatment is designed to remove certain elements, so it is entirely possible that a plant employs several tertiary treatment processes, depending on the composition and characteristics of the wastewater flow that remove specific types of residuals by filtration (removal of suspended or colloidal solids), adsorption, chemical oxidation (removal of organics, nitrogen, phosphorus), ozonation, chlorination and UV radiation (disinfection). All these processes have their place in overall wastewater treatment scheme.

Effluent from primary clarifiers flows to the biological reactor, which is physically divided into five zones by baffles and weirs. In sequence, these zones are (i) anaerobic fermentation zone (characterised by very low dissolved oxygen levels and the absence of nitrates), (ii) anoxic zone (low dissolved oxygen levels but nitrates present), (iii) aerobic zone (aerated), (iv) secondary anoxic zone and (v) final aeration zone. The function of the first zone is to condition the group of bacteria responsible for phosphorus removal by stressing them under low oxidation-reduction conditions, which results in a release of phosphorus equilibrium in the cells of the bacteria. On subsequent exposure to an adequate supply of oxygen and

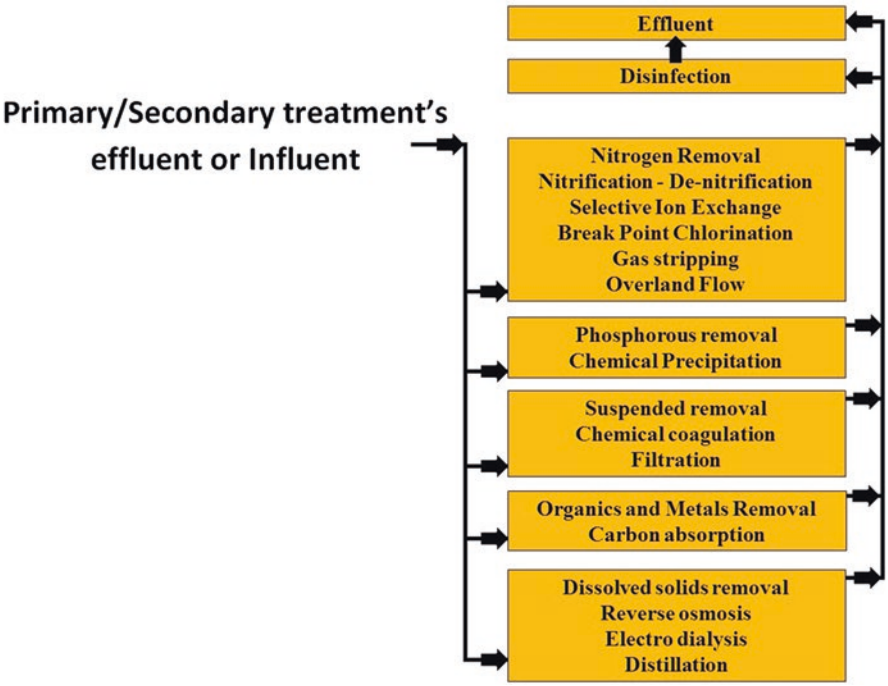


Fig. 6.18 Tertiary treatment

phosphorus in the aerated zones, these cells rapidly accumulate phosphorus considerably in excess of their normal metabolic requirements. Phosphorus is removed from the system with the waste activated sludge.

Most of the nitrogen in the influent is in the ammonia form, and this passes through the first two zones virtually unaltered. In the third aerobic zone, the sludge age is such that almost complete nitrification takes place, and the ammonia nitrogen is converted to nitrites and then to nitrates. The nitrate-rich mixed liquor is then recycled from the aerobic zone back to the first anoxic zone. Here denitrification occurs, where the recycled nitrates, in the absence of dissolved oxygen, are reduced by facultative bacteria to nitrogen gas, using the influent organic carbon compounds as hydrogen donors. The nitrogen gas merely escapes to atmosphere. In the second anoxic zone, those nitrates which were not recycled are reduced by the endogenous respiration of bacteria. In the final re-aeration zone, dissolved oxygen levels are again raised to prevent further denitrification, which would impair settling in the secondary clarifiers to which the mixed liquor then flows.

In many situations, where the risk of public exposure to the reclaimed water or residual constituents is high, the intent of the treatment is to minimise the probability of human exposure to enteric viruses and other pathogens (Table 6.4). Effective disinfection of viruses is believed to be inhibited by suspended and colloidal solids in the water; therefore, these solids must be removed by advanced treatment before the disinfection step.

Because advanced treatment usually follows high-rate secondary treatment, it is sometimes referred to as tertiary treatment. However, advanced treatment processes are sometimes combined with primary or secondary treatment (e.g. chemical

Table 6.4 Infectious agents potentially present in untreated domestic wastewater

S. No.	Pathogen	Disease
Bacteria		
1.	*Escherichia coli* (enterotoxigenic)	Gastroenteritis
2.	*Leptospira* (spp.)	Leptospirosis
3.	*Salmonella typhi*	Typhoid fever
4.	*Vibrio cholera*	Cholera
Protozoan		
1.	*Balantidium coli*	Balantidiasis
2.	*Entamoeba histolytica*	Amoebiasis (amoebic dysentery)
Helminths		
1.	*Ascaris lumbricoides*	Ascariasis
2.	*Taenia solium*	Taeniasis
Viruses		
1.	Enteroviruses (72 types, e.g. polio, echo, and Coxsackie viruses)	Gastroenteritis
		Heart anomalies
		Meningitis
2.	Hepatitis A virus	Infectious hepatitis

addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (e.g. overland flow treatment of primary effluent).

6.6.4.1 Filtration

This process removes residual unsettled microorganisms flocs and any other suspended solids. Two main types are used: granular filtration, using sand filters or multimedia filters, and membrane filtration.

6.6.4.2 Carbon Adsorption

Several soluble organic materials can resist a full secondary treatment and filtration persisting in the effluent. These materials, known as refractory organics, are removed by adsorbing them on activated carbon.

6.6.4.3 Chemical Oxidation

The chemical oxidation processes utilising activation of H_2O_2 by Fe(II) salts are referred to as Fenton's reactions. Fenton's reaction causes the dissociation of the oxidant and the formation of highly reactive hydroxyl radicals that attack and destroy organic pollutants. Fenton's reagent is a mixture of H_2O_2 and ferrous iron, which catalyses the formation of hydroxyl radicals according to the reaction

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

6.6.4.4 Phosphorus Removal

Phosphorus is typically found as monohydrogen phosphate (HPO_4^{2-}) in wastewater. In order to prevent or reduce eutrophication in wastewater, phosphorus is chemically precipitated. This reaction is usually produced using one of these three compounds: ferric chloride, alum or lime. The process itself requires a reaction basin and a settling tank. In case of using ferric chloride, the aeration tank serves as reaction basin, and the secondary clarifier can be used as settling tank, so performing this process as the secondary treatment takes place.

6.6.4.5 Nitrogen Control

In order to control algal growth in the effluent receiver, it is necessary on many occasions to remove nitrogen from wastewater. This process can be achieved biologically or chemically. The biological process is known as nitrification/denitrification, while the chemical process is called ammonia stripping.

6.6.5 Disinfection

Primary, secondary and even tertiary treatment cannot be expected to remove 100 % of the incoming waste load, and as a result, many organisms still remain in the waste stream. To prevent the spread of waterborne diseases and also to minimise public health problems, regulatory agencies may require the destruction of pathogenic organisms in wastewaters. While most of these microorganisms are not pathogens,

pathogens must be assumed to be potentially present. Thus, whenever wastewater effluents are discharged into receiving waters which may be used for water supply, swimming or shellfishing, the reduction of bacterial numbers to minimise health hazards is a very desirable goal. Disinfection is the treatment of the effluent for the destruction of all pathogens.

The effectiveness of disinfection depends on the quality of the water being treated, the type of disinfection being used, the disinfectant dosage and other environmental variables. Cloudy water will be treated less successfully since solid matter can shield organisms, especially from ultraviolet light or if contact times are low. Common methods of disinfection include ozone, chlorine or ultraviolet light.

6.6.5.1 Chlorination

Disinfection normally involves the injection of a chlorine solution at the head end of a chlorine contact basin. Chlorine contact basins are usually rectangular channels, with baffles to prevent short-circuiting, designed to provide a contact time of about 30 min. However, to meet advanced wastewater treatment requirements, a chlorine contact time of as long as 120 min is sometimes required for specific irrigation uses of reclaimed wastewater. The chlorine dosage depends upon the strength of the wastewater and other factors, but dosages of 5–15 mg/l are common. The treatment of wastewaters for the destruction of pathogens demands the use of practical measures that can be used economically and efficiently at all times on large quantities of wastewaters which have been treated to various degrees. The bactericidal effects of chlorine and other disinfectants are dependent upon pH, contact time, organic content and effluent temperature. The prevalent use of chlorine has come about because chlorine is an excellent disinfecting chemical and, until recently, has been available at a reasonable cost. However, the rising cost of chlorine coupled with the fact that chlorine even at low concentrations is toxic to fish and other biota as well as the possibility that potentially harmful chlorinated hydrocarbons may be formed has made chlorination less favoured as the disinfectant of choice in wastewater treatment.

6.6.5.2 Ozonation

Ozone is produced when oxygen (O_2) molecules are dissociated by an energy source into oxygen atoms and subsequently collide with an oxygen molecule to form an unstable gas, ozone (O_3), which is used to disinfect wastewater. Most wastewater treatment plants generate ozone by imposing a high-voltage alternating current (6–20 kV) across a dielectric discharge gap that contains an oxygen-bearing gas. Ozone is generated on site because it is unstable and decomposes to elemental oxygen in a short period of time after generation. Ozone is a very strong oxidant and virucide.

When ozone decomposes in water, the free radicals hydrogen peroxy (HO_2) and hydroxyl (OH) that are formed have great oxidising capacity and play an active role in the disinfection process. It is generally believed that the bacteria are destroyed because of protoplasmic oxidation resulting in cell wall disintegration (cell lysis). The effectiveness of disinfection depends on the susceptibility of the target organisms, the contact time and the concentration of the ozone.

Ozone is considered to be safer than chlorine because unlike chlorine, which has to be stored on site, ozone is generated on site as needed. Ozone also produces less disinfection by-product than chlorination.

6.6.5.3 UV Radiation

UV light can be used instead of other chemical compounds. Because no chemicals are used, the treated water has no adverse effect on organism that later consume it, as may be the case with other methods. UV radiation causes damage to the genetic structure of bacteria, viruses and other pathogens, making them incapable of reproduction. Ultraviolet light has recently undergone studies to determine its effectiveness and cost when used at large wastewater treatment plants.

Both ozone and ultraviolet light, as well as being an effective disinfecting agent, leave no toxic residual. Ozone will additionally raise the dissolved oxygen level of water. However, ozone must be generated and has only recently begun to compete favourably with chlorination in terms of economics. Therefore, the increased use of ozone (ozonation) or ultraviolet light as a disinfectant in the future is a distinct possibility in wastewater disinfection.

6.7 Effluent Storage

Although not considered a step in the treatment process, a storage facility is, in most cases, a critical link between the wastewater treatment plant and the irrigation system. Storage is needed for the following reasons:

(i) To equalise daily variations in flow from the treatment plant and to store excess when average wastewater flow exceeds irrigation demands; includes winter storage.
(ii) To meet peak irrigation demands in excess of the average wastewater flow.
(iii) To minimise the effects of disruptions in the operations of the treatment plant and irrigation system. Storage is used to provide insurance against the possibility of unsuitable reclaimed wastewater entering the irrigation system and to provide additional time to resolve temporary water quality problems.

6.8 Reliability of Conventional and Advanced Wastewater Treatment

Wastewater reclamation and reuse systems should contain both design and operational requirements necessary to ensure reliability of treatment. Reliability features such as alarm systems, standby power supplies, treatment process duplications, emergency storage or disposal of inadequately treated wastewater, monitoring devices and automatic controllers are important. From a public health standpoint, provisions for adequate and reliable disinfection are the most essential features of the advanced wastewater treatment process. Where disinfection is required, several reliability features must be incorporated into the system to ensure uninterrupted chlorine feed.

6.9 Consideration for Future Use

Research activities to improve wastewater handling have been focused on optimising the built systems and the development of new methods (Table 6.5). A change in research priorities has gradually occurred in order to comply with sustainability principles. At present new technologies should meet requirements of sustainable development and multidisciplinary approach (Fig. 6.19). Further, the following approaches are being applied:

(a) Production technology: safe personal care products, pharmaceuticals and drugs
(b) Communication: interactions between consumers, water companies, etc.
(c) Technology development: membrane, removal of microorganics, deammonification, phosphorus recovery, etc.
(d) Recipient effects: new threats
(e) Resources recovery: phosphorus recovery

Future goals may be categorised as follows:

1. Development and optimisation of new methods and process configurations for resource-effective wastewater treatment
2. Tests for development of equipment for wastewater treatment and separation technology
3. Development of new methods/process configurations for drinking water production from wastewater

Table 6.5 Changes in priorities of wastewater treatment with time

Time	Main problem	Remedies
From 1930	Visible pollutants	Mechanical treatment
From 1950	Low oxygen contents in recipient	Secondary/biological treatment
From 1970	Eutrophication of lakes	Tertiary/chemical treatment
From 1990	Marine eutrophication	Removal of nitrogen/phosphorus
Present and future	Recovery of resources (as phosphorus and energy)	Eco-cycling
From 2025 (predicted)	Deposition of sludge	Implementation of Agenda 21
	'Unwanted substances' in aquatic environment (pharmaceuticals, synthetic chemicals, hormones) New unknown??	Sustainable technologies
		Modified sludge handling
		Increased public participation/ responsibility
		Development of new wastewater treatment technologies (Anammox)

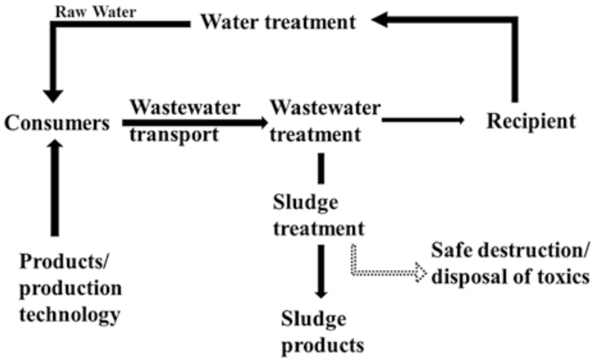


Fig. 6.19 Multidisciplinary approach in water and wastewater treatment

Wastewater treatment research which has the potential to advance safe, reliable and cost-effective technologies to reuse effluents should be an international priority. Emerging technologies such as on-line sensors with real-time feedback will certainly play a major role in water reuse in the near future. Advances in membrane technologies will also be critical in lowering energy needs and increasing water recovery rates. These technological advances should be prioritised comprehensively for achieving the correct water quality for the application needed. Creating ultra-high purity water for irrigation, toilet flushing and washing laundry does not make good sense. Therefore, the future will lie squarely in fit-for-purpose treatment and more distributed systems that can be interlinked and autonomously controlled.

References

Abdel-Raoufa N, Al-Homaidanb AA, Ibraheem IBM (2012) Microalgae and wastewater treatment. Saudi J Biol Sci 19(3):257–275

Asthana M, Kumar A, Vikrant P, Gupta P (2014) Tannery effluents de-colourization efficiency of bacterial isolates from River Yamuna and industrial effluents. Int J Curr Microbiol Appl Sci 3(5):869–880

Bandaru KSVSR, Murthy DVS, Krishnaiah K (2007) Some hydrodynamic aspects of 3-phase inverse fluidized bed. China Particuol 5(5):351–356

Bhargava DS (2008) Dissolved oxygen Sag analysis for a settling fields overlapping type multiwastewater-outfall. Environ Springer Sci Bus Media 28:128–136

Frobisher M, Hinsdill RD, Crabtree KT, Goodheart CR (1974) Fundamental of microbiology, 9th edn. W.B. Saunders, Philadelphia, pp 120–152

Gupta P, Kumar A, Khatri A, Asthana M (2014) Acid green dye decolourizing bacteria from Yamuna water and textile effluents. Int J Environ Sci 5(3):482–490

Khalid A, Arshad M, Anjum M, Mahmood T, Dawson L (2011) The anaerobic digestion of solid organic waste-review. Waste Manag 31(8):1737–1744

Kumar A, Asthana M, Gupta P, Yadav S, Sharma D, Singh KN, Kumar S (2015) 16SrRNA sequencing of Dye decolourizing bacteria isolated from soil. Bioinformation 11(1):1–5

Marinescu M, Dumitru M, Lacatusu A (2009) Biodegradation of petroleum hydrocarbons in an artificial polluted soil. Res J Agric Sci 41(2):157–167

Morel A, Diener S (2006) Greywater management in low and middle-income countries, review of different treatment systems for households or neighbourhoods (= SANDEC News No.14/06). Swiss Federal Institute of Aquatic Science (EAWAG), Department of Water and Sanitation in

Developing Countries (SANDEC), Duebendorf, http://www.sswm.info/sites/default/files/reference_attachments/MOREL%20and%20DIENER%202006%20Greywater%20Management.pdf. Accessed: 29 Dec 2015
Neyens E, Baeyens J, Dewil R, De Heyder B (2004) Advanced sludge treatment affects extracellular polymeric substances to improve activated sludge dewatering. J Hazard Mater 106B:83–92
Noorjahan CM (2014) Physicochemical characteristics, identification of bacteria and biodegradation of industrial effluent. J Bioremed Biodegrad 5(3):1–5
Rice EW, Baird RB, Eaton AD, Clesceri LS (2012) Standard methods for the examination of water and wastewater, 22nd edn. American public health association, Washington, DC
Singh U, Maheshwari R, Swami VK, Chauhan V (2012) Integrated effluent treatment in textile industries-feasibility study. Int J Chem Life Sci 01(01):1018–1025
Thomann RV, Mueller JA (1987) Principles of surface water quality modeling and control. Harper International Edition, New York
Vandevivere P, De Baere L, Verstraete W (2003) Types of anaerobic digesters for solid wastes. In: Mata-Alvarez J (ed) Biomethanization of the organic fraction of municipal solid wastes. IWA Publishing, Barcelona, pp 111–140

Suggested Further Readings

Hammer MJ, Hammer MJ Jr (2000) Water and wastewater technology, 3rd edn. Prentice Hall of India Pvt Ltd, New Delhi
Hill MK (1997) Understanding environmental pollution. Cambridge University Press, New York
Jogdand SN (2003) Environmental biotechnology (industrial pollution management), 2nd edn. Himalaya Publishing House Mumbai, India
Olguin EJ, Sanchez G, Hernandez E (2000) Environmental biotechnology and cleaner bioprocesses, 1st edn. Taylor and Francis, London
Rowe DR, Abdel-Magid IM (1995) Handbook of wastewater reclamation and reuse. CRC Lewis Publisher, Boca Raton