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ENVIRONMENTAL BIOTECHNOLOGY

T. Srinivas

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(Late Prof. M.V. Venkata Rao)

dedicated to

my “true” exemplary teacher

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Foreword

Nature is God's creation and man has no right to meddle with it. It is said "Man cannot command nature except by obeying it." Nature is bountiful and has natural assimilative and self purification capacities. However if nature is overtaxed with pollution levels beyond its natural assimilative and self purification capacities, it would lead to environmental degradation.

The development activities, though for man's betterment, do have the negative aspects like generation of pollutants and wastes leading to environmental degradation.

Environmental Biotechnology is a subject which deals with engineering applications of principles of microbiology in solving environmental problems. In this book, some of the topics like biological treatment of industrial and municipal wastewaters, solid waste management, bioremediation etc. with a dimension to suit to the spectrum of Environmental Biotechnology have been dealt within scholarly detail.

This book is no doubt, a qualitative contribution to the existing corpus of scholarly knowledge on Environmental Biotechnology.

Prof. M. Gangadhara Rao, Ph.D.
Vice-Chancellor

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Message

Advances in technology have enabled modern man to have access to a wide range of material comforts which were unimaginable even a few decades back. Yet the appetite for even more comforts remains unsatiated. The ever-growing demands of man have put an unprecedented burden on natural resources especially those related to energy production. The situation is characterized by rapidly depleting natural resources and the release of gargantuan amounts of waste products by a variety of industries, the transportation sector and urban households. The three most important elements of our environment namely water, air and earth are reeling under the accumulating burden of these pollutants, unable to clean them up rapidly enough by natural processes. This has already caused the extinction of thousands of species of animal and plant life. The threat to the continued existence of mankind itself is non-trivial.

Several physical and chemical methods have been developed to deal with the problem of environmental pollution often with great success. Use of biological means to do the same job is an interesting, if not a novel, idea that is finding increasing acceptance. Intensive researches have led to the accumulation of a wide body of knowledge concerning these biotechnological methods. The present book is a comprehensive account of these techniques in so far as they are concerned with the treatment of wastewaters and bioremediation of soils.

In this book, a detailed listing of the physical, chemical and biological characteristics of wastewater is followed by a description of the biological methods used to treat the wastewaters. Subsequent chapters deal with sludge treatment, solid waste treatment and finally bioremediation of contaminated soils. Primarily aimed as a text book on the subject for undergraduate as well as post graduate students of environmental biotechnology, the book is a valuable addition to the literature on the subject. Written in a simple and lucid style, the book should help the reader to quickly master the various aspects of biological treatments of polluted water and soil. Emphasis on design aspects coupled with a large number of solved problems as well as chapter-end workouts for the student have considerably added to the usefulness of the book. The author Dr. T. Srinivas, an erudite scholar and a diligent researcher, deserves to be congratulated on this laudable effort.

VVKutumbarao

December 12, 2007

Prof. V.V. Kutumbarao
Principal

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Preface

Environmental Biotechnology is the engineering application of principles of microbiology to solve environmental problems.

Aspects in Environmental Biotechnology constitute

- Biological treatment of industrial and municipal wastewaters.
- Enriching drinking water quality.
- Restoration of pre existing flora and fauna of land areas contaminated with hazardous materials.
- Safeguarding rivers, lakes, estuaries and coastal wasters from environmental contaminants.
- Prevention of water borne, water based and air borne diseases etc.

In this book some of the multifaceted topics that constitute ***Environmental Biotechnology*** are dealt with.

Environmental Biotechnology employs microorganisms to remove contaminants from wastewater. There is a growing realization world over that Biotechnology along with Environmental Engineering is going to be the major thrust area in the new millennium. The use of Biotechnology in design, control and optimization of biological wastewater treatment is steadily increasing, and this book specifically gives a comprehensive idea of this rapidly growing field.

Environmental Biotechnology is well suited for students of B.E./B.Tech Biotechnology and Environmental Management.

The author is deeply indebted to Late Prof. M.V. Venkata Rao, Retd. Head of the Department of Civil Engineering, Andhra University, for his blessings and through whose spirit this book took the present form.

The author sincerely expresses his deep sense of reverence to Dr. M.V.V.S. Murti, President, GITAM University, his gratitude to Prof. M. Gangadhara Rao, Vice-chancellor, GITAM University, Dr. V.V. Kutumbarao, Director, College of Engineering, GITAM, Prof. R. Sinha, Head, Dept. of Biotechnology, College of Engineering, GITAM and Prof. T. Shivaji Rao, Director, Centre for Environment, GITAM for their perennial encouragement in bringing out this book.

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The author is extremely grateful to Prof. A. Kameswara Rao, Chaitanya Engineering College, for his constant encouragement, without which this work would not have been completed. The author expresses his special thanks to Sri. M. Raja Roy, Assistant Professor, Dept. of Mechanical Engineering, ANITS, for his contribution in diagrammatic representations of this book.

The author is also thankful to colleagues of the Departments of Biotechnology (Engg.), and Environmental Studies, GITAM University, who have extended their cooperation in bringing out this book.

The author wishes to keep on record, his affectionate thanks to his better half, Dr.T.Usha Madhuri, Assistant Professor, Dept. of Civil Engineering, Andhra University, for her kind cooperation. The author wishes to express his indebtedness to his parents Sri. T.S.K. Bhagavanulu, and (Late) Smt. T. Surya Kumari, for their long lasting blessings.

The author wishes to thank the New Age International Publishers, for their keen interest in bringing out this book and thrusting responsibility.

Dr. T. Srinivas

Contents

1

Water and Wastewater

1.1 HYDROLOGICAL CYCLE

Water, one of the abundant compounds found in nature, is covering approximately three-fourths of the surface of the earth. Over 97% of the total quantity of water is in the oceans and other saline bodies of water and is not readily available for our use. Over 2% is tied up in polar ice caps and glaciers and in atmosphere and as soil moisture, which is inaccessible. An essential element for livelihood, domestic, industrial and agricultural activities, we have to depend upon only 0.62% of water found in fresh water lakes, rivers and groundwater supplies, irregularly and non-uniformly distributed over the vast area of the globe.

Solar radiation causes evaporation. Through evaporation from surface waters or by evapotranspiration from plants, water molecules convert into atmospheric vapour. Atmospheric water condenses and falls to the earth as rain and snow. Once on the earth's surface, water flows into streams, lakes and eventually oceans or percolates into the soil and into aquifers.

Water in nature is most nearly pure in its evaporation state. Gases as SO_2, NO_x may find their way into it at the very moment of condensation causing *acid rain*. Impurities are added as the liquid water travels through the remainder of the hydrological cycle and comes into contact with materials in the air and on or beneath the surface of the earth. Human activities contribute industrial and domestic wastes and agricultural chemicals to water.

The impurities accumulated by water throughout the hydrological cycle and as a result of human activities may be in both suspended and dissolved form. Suspended material consists of particles larger than molecular size that are supported by buoyant and viscous forces within water. Hence it is more common in water bodies in motion as river waters at flood time. Dissolved material consist of molecules or ions that are held by the molecular structure of water. They will be present in higher concentrations in ground waters due to the prolonged contact of percolating water with various beds. Colloids are very small particles that technically are suspended impurities but often exhibit many of the characteristics of dissolved substances.

1.2 WASTEWATER

Water is an essential ingredient of life. House as well as industry consume water and give out wastewater. Sanitary sewage is of domestic origin and its quantity depends on the number of people and nothing to do with the weather. Hence it is called *Dry Weather Flow* (DWF) . On the other hand runoff from catchments (particularly from roofs and roads) because of heavy rainfall is called *Storm Water* and is directly dependent on the intensity and duration of rainfall.

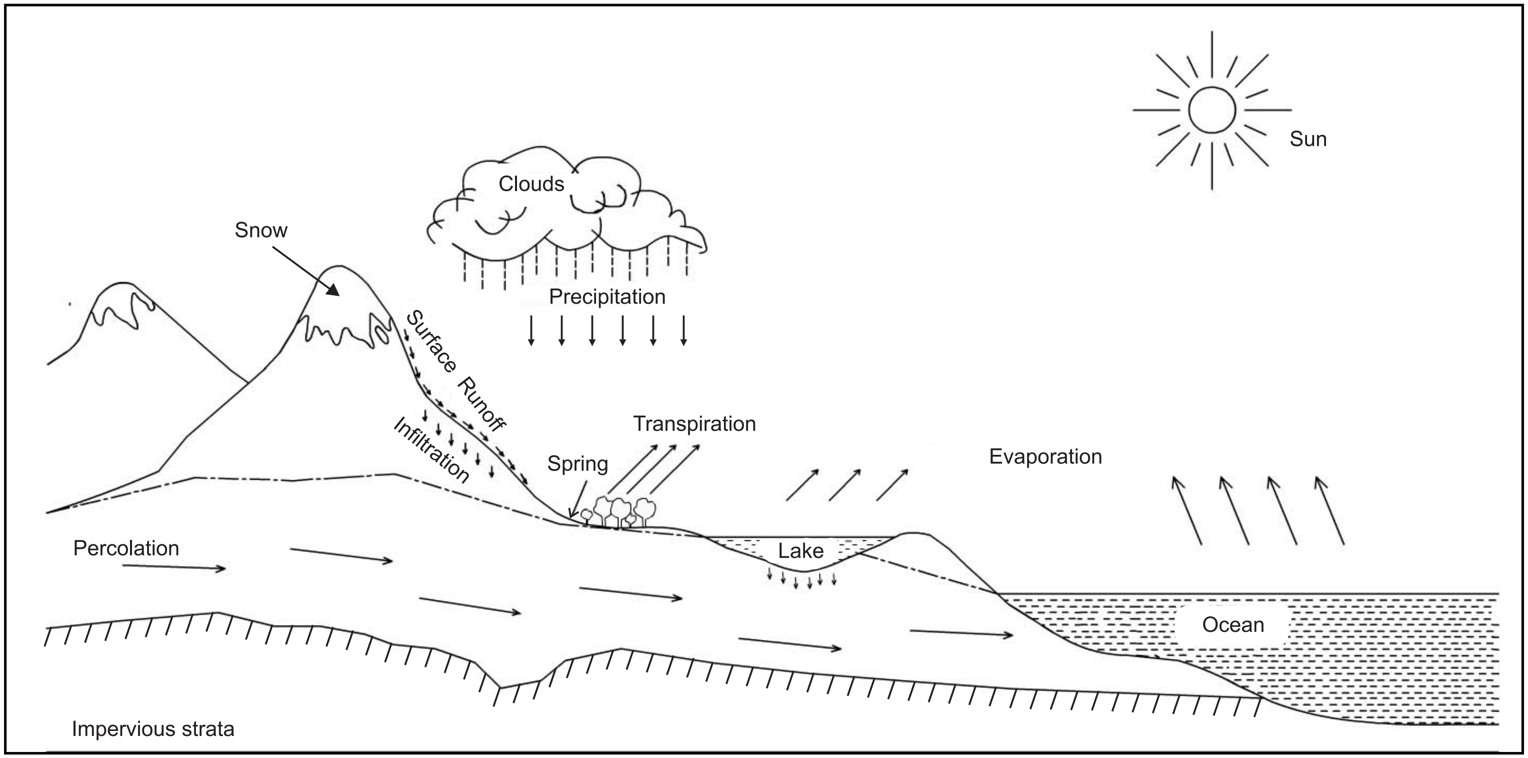

Fig. 1.1: Hydrological cycle

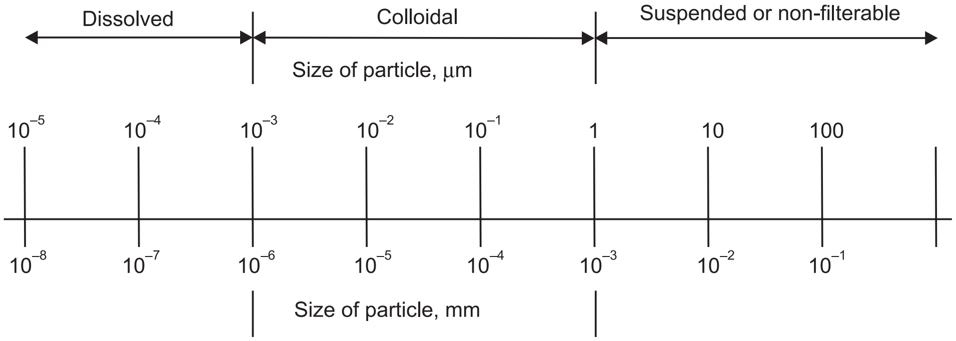

Fig. 1.2: Particles distribution (Size classification of solids)

Industrial wastewater is the effluent delivered out of a particular industry. Its quality and quantity depends upon nature of industry, raw materials used, manufacturing process and house keeping. Their characteristics vary widely from industry to industry.

Water pollution is defined as contamination of water or alteration of the physical, chemical or biological properties of natural water. Water is said to be polluted when it changes its quality or composition either naturally or as a result of human activities, thus becoming unsuitable for domestic, agricultural, industrial, recreational uses and for the survival of wildlife.

A water pollutant can be defined as an agent affecting aesthetic, physical, chemical and biological quality and *wholesomeness* of water.

1.3 PHYSICAL PARAMETERS

1.3.1 Suspended Solids

Solids suspended in water may consist of inorganic or organic particles. Inorganic solids such as clay, silt and other soil constituents are common in running surface water as rivers and streams. Organic material such as plant fibers and biological solids as algal cells and bacteria are also common constituents of surface waters. Because of the filtering capacity of the soil, and because of stagnation as in wells, suspended material is a rare constituent of groundwater. Sanitary sewage usually contains large quantities of suspended solids that are mostly organic in nature. Suspended solids are aesthetically displeasing and provide adsorption sites for chemical and biological agents. Suspended organic solids degrade biologically resulting in objectionable by-products of foul odours.

Total solids of a sample is measured by evaporating the sample to dryness at a temperature of $105° \pm 1°C$ and weighing the residue. The suspended fraction of the solids in a water sample can be determined by filtering the water, drying the residue at $\approx 104°C$. The organic content of both total and suspended solids can be determined by heating the residues at 600°C for one hour. The organic fraction of the residues will be converted to carbon dioxide, water vapour and other gases. The remaining material will represent the inorganic or fixed residue.

1.3.2 Turbidity

Turbidity is the property of absorption of light or its scattering by suspended material in water. Both absorption and scattering are influenced by size and surface characteristics of the suspended material. Turbidity may not be caused by transparent suspended solids. Colloidal material of clay, silt, rock fragments and metal oxides from the soil, vegetable fibres and microorganisms cause turbidity. Also soaps, detergents and emulsifying agents produce stable colloids that result in turbidity. Although turbidity measurements are not commonly run on wastewater, discharges of wastewater may increase the turbidity of natural bodies of water.

The colloidal material associated with turbidity provides adsorption site for chemicals, that may be harmful or cause undesirable tastes and odours and shield pathogenic biological organisms from disinfection.

Jackson turbidity unit (JTU) was based on light absorption being equal to the turbidity produced by 1 mg SiO_2 in 1 litre of distilled water. Nephelometric turbidity unit (NTU) is based on light scattering principle.

1.3.3 Colour

Pure water as rain water is colourless. But water is a universal solvent and is often coloured by many substances. Running water carries suspended solids which cause apparent colour. Water whose colour is due to suspended matter is said to have apparent colour. Apparent colour fades out when suspended solids settle. Colour contributed by dissolved solids is known as true colour which remains permanently.

After contact with organic debris such as leaves, weeds and wood, water picks up tannins, humic acid and humates to take a yellowish brown hue. Iron oxide causes reddish water and manganous oxide gives brown or blackish water.

Fresh sanitary sewage is grey in colour and its colour deepens with time. Stale or septic sewage is dark in colour. At a temperature of 20°C, fresh sewage becomes stale in 2 to 6 hours depending on the concentration of organic matter. Industrial wastes from textile and dyeing operations, pulp and paper wastewaters, food processing waste liquids, mining, refining and slaughterhouse operations add to colour of receiving streams.

Colour is a visible pollutant. Coloured water is not aesthetically acceptable for domestic as well as industrial use. Highly coloured water may not be accepted for laundering, dyeing, papermaking, beverage manufacturing, dairy production, food processing, textile and plastic production.

Methods involving measurement of intensity of colouration is based on comparison with standardized coloured materials. Results are expressed in true colour units (TCUs). One true colour unit is equivalent to the colour produced by 1 mg of platinum in the form of chloroplatinate ions along with 0.5 mg of cobalt chloride being dissolved in one litre of distilled water.

1.3.4 Taste and Odour

Substances which comes into prolonged contact with water may impart perceptible taste and odour. Minerals, metals and salts from the soil, end products from biological reaction and constituents of wastewater attribute taste and odour to water. For domestic consumption water should be free from odour and its taste should be agreeable.

Threshold Odour Number (TON) is an index of odour.

Varying amounts of odourous water are poured into containers and diluted with enough odour free distilled water to make a 200 mℓ mixture.

$\text{TON} = \frac{A+B}{A}$ where A is the volume of odourous water (mℓ) and B is the volume of odour free distilled water required to produce a 200 mℓ mixture. (Max. acceptable value of TON is 3 for domestic consumption).

Odour is mainly caused because of gases of decomposition of organic matter. Fresh sanitary sewage has mild, earthy, inoffensive odour or it may be even odourless. Because of anaerobic decomposition of proteins and other organic matter rich in nitrogen, sulphur and phosphorous, foul smelling and highly odourous gases as ammonia, hydrogen sulphide, mercaptans ($C_a\ H_b\ S_c$) and skatol ($C_x\ H_y\ N_z$) are produced.

Odour causes more a psychological stress than any direct harm. Offensive odours reduce appetite for food, lower water consumption, impair respiration, nausea, result in vomitting and mental perturbation and in extreme cases leads to deterioration of personal and community pride, interfere in human relations discouraging capital investments, lowering socio-economic status and deterring growth and decline in value and sales.

1.3.5 Temperature

Temperature is one of the most important parameters. *Temperature is a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller and a killer*. It affects the self purification of streams. Rise in temperature enhances toxicity of poisons and intensity of odour besides changing the taste. Also increase in temperature causes growth of undesirable water plants and wastewater fungus. It influences the biological species present and their rates of biological activity. Temperature has an effect on most chemical reactions that occur in natural water systems. Temperature also has a pronounced effect on the solubilities of gases in water. Aerobic digestion ceases at a temperature greater than 50°C. At less than 15°C anaerobic digestion is affected as methane bacteria become inactive.

Temperature affects the reaction rates and solubility levels of chemicals. Most chemical reactions involving dissolution of solids are accelerated by increased temperatures. The solubility of gases, on the other hand, decreases at elevated temperatures.

1.4 CHEMICAL PARAMETERS

Total dissolved solids, alkalinity, hardness, fluorides, metals, organics and nutrients are chemical parameters of concern in water quality management.

1.4.1 Total Dissolved Solids (TDS)

Dissolved solids result mainly because of prolonged contact of water with the salts of different catchments. They may be of organic or inorganic origin . Inorganic substances are minerals and metals. Decay products of vegetable and animal origin give rise to organic matter. Dissolved salts may produce colour, taste and odour of which some are objectionable. Distilled water or rain water free from dissolved solids is preferred for industrial operations as steam production and manufacturing of soft drinks. Domestic water should be colourless, odourless but of agreeable taste. Presence of dissolved solids alone gives taste. However a concentration greater than 500 to 1000 mg/ℓ of dissolved salts may give rise to bitter taste and laxative effect.

1.4.2 Alkalinity

Alkalinity is the ability of water to neutralize acids. CO_3^{2-}, HCO_3^-, OH^-, $H\ SiO_3^-$, $H_2BO_3^-$, HPO_4^- and NH_3 which are quite common in atmosphere and soil contribute to alkalinity. These compounds result from the dissolution of mineral substances in the soil and atmosphere. Phosphates from detergents and fertilizers and insecticides of agricultural land may also cause alkalinity.

Alkalinity is classified as (i) hydroxide alkalinity or *caustic alkalinity* (ii) carbonate alkalinity and (iii) bicarbonate alkalinity. Hydroxide alkalinity occurring at a pH greater than 8.3 (generally above 10) causes bitter taste, affects the lacrimal fluid around the eye ball of swimmers, whereas bicarbonate alkalinity occurring below a pH of 8.3 (but above 4.5) mainly causes scale formation in boilers and incrustations in pipe lines.

1.4.3 Hardness

Waters which readily give lather with soap are soft waters. Those which do not readily give lather are hard waters. Hardness is due to dissolved divalent metallic cations as Ca^{++}, Mg^{++}, Fe^{++}, Mn^{++} and Sr^{++} and anions as bicarbonates, chlorides and sulphates of which the most abundant in natural waters are *Calcium* and *Magnesium*. Hence for all practical purposes, hardness is the sum of the calcium and magnesium ions. Carbonate hardness is due to bicarbonates of Calcium and Magnesium which can be easily removed by simple means as boiling and hence is called temporary hardness. Alkalinity alone causes carbonate hardness.

Noncarbonate hardness due to chlorides and sulphates of Calcium and Magnesium cannot be removed that easily and hence is called permanent hardness.

Greater soap consumption by hard waters is an economic loss. Lathering occurs only when all the hardness ions are precipitated and softened by the soap. Boiler scale formed because of carbonate hardness precipitation may cause considerable heat loss as the scale is an insulator.

Table 1.1: Classification of hardness

Nature of water	*Range of hardness*
Soft	0 – 75 mg/ℓ as $CaCO_3$
Moderately hard	75 – 150 mg/ℓ as $CaCO_3$
Hard	150 – 300 mg/ℓ as $CaCO_3$
Very hard	> 300 mg/ℓ as $CaCO_3$

1.4.4 Fluoride

It is an ingredient of igneous and sedimentary rocks. Fluoride is rarely found in appreciable quantities in surface waters but appears in certain ground waters. Concentrations of approximately 1 mg/ℓ in drinking water help to prevent dental cavities in children (*dental carries*). During the formation of permanent teeth, fluoride combines chemically with tooth enamel resulting in harder and stronger teeth that are more resistant to decay. Excessive intakes of fluoride can result in discolouration of enamel of teeth called *mottling* (Dental Fluorosis). Excessive dosages of fluoride can also result in fluorosis of bones and other skeletal abnormalities (Skeletal Fluorosis).

1.4.5 Inorganic Salts

Inorganic salts, which are present in most industrial wastes as well as in natural soils, render the water hard and make it undesirable for industrial, municipal and agricultural use. Salt laden waters deposit scales on municipal water distribution pipelines result in increase resistance to flow and lower the overall capacity of the pipes. Salts of nitrogen and phosphorous promote the growth of microscopic plant life (algae) resulting in *eutrophication* of lakes.

1.4.6 pH

pH is *potential Hydrogen* i.e., the negative logarithm of hydrogen ion concentration. It is an important quality parameter of both waters and wastewaters. The pH range suitable for the survival and nourishment of most biological life is quite narrow and critical i.e., 6.5 to 8.5. Extreme pH values are unfavourable for biological treatment.

1.4.7 Acids and Alkalies

Acids and alkalies discharged by chemical and other industrial plants make a stream undesirable not only for recreational uses as swimming and boating, but also for propagation of fish and other aquatic life. High concentrations of mineral acids lower the pH well below 4.5. Similarly extreme alkalinity causes eye irritation to swimmers.

1.4.8 Chlorides

Chlorides in natural water result from the leaching of chloride containing rocks and soils with which the water comes in contact and in coastal areas from sea water intrusion. In addition, agricultural, industrial and domestic wastewaters discharged into surface waters are a source of chlorides. Human excretions contain about 6 g of chlorides per person per day on average. Conventional methods of waste treatment do not remove chlorides.

1.4.9 Metals

All metals are soluble to some extent in water. Metals harmful in small concentrations are termed toxic. Calcium and Magnesium cause hardness. Iron concentrations of > 0.3 mg/ℓ and Manganese > 0.05 mg/ℓ may cause colour problems. Some bacteria use iron and manganese compounds as an energy source and the resulting *slime growth* may produce taste and odour problems.

Toxic metals: Toxic metals are Arsenic, Barium, Cadmium, Chromium, Lead, Mercury and Silver. Cumulative toxins are Arsenic, Cadmium, Lead and Mercury.

1.4.10 Heavy Metals

Trace quantities of many metals, such as Nickel, Manganese, Chromium, Cadmium, Zinc, Copper and Iron find their way into water. Some of these metals in very small concentrations are necessary for the growth of biological life, but harmful in higher concentrations.

1.4.11 Nutrients

Nutrients are elements required to the growth and reproduction of plants and animals and aquatic flora and fauna.

1.4.12 Nitrogen

Nitrogen is a constituent of proteins, chlorophyll and many other biological compounds. Upon the death of plants or animals, complex organic matter is broken down to simple forms by bacterial decomposition. Proteins are converted to amino acids and further reduced to ammonia (NH_3). If oxygen is present, the ammonia is oxidized to nitrite (NO_2^-) and then to nitrate (NO_3^-). Other sources of nitrogen in aquatic systems include animal wastes, chemical wastewaters (particularly chemical fertilizers) and domestic wastewater discharges. Nitrite has a greater affinity for haemoglobin than oxygen and thus replaces oxygen in the blood complex. The body is denied essential oxygen and in extreme cases, the victim (baby less than 6 months old) suffocates. Because oxygen starvation results in a bluish discolouration of the body, nitrate poisoning has been referred to as the "blue baby" syndrome, although the correct term is "*methaemoglobinemia*".

1.4.13 Phosphorous

Phosphorous appears exclusively as phosphate (PO_4^{3-}) in aquatic environments. Phosphate is a constituent of soils and is used extensively in fertilizer to replace and/or supplement natural quantities on agricultural lands. Phosphate is also a constituent of animal waste and may become incorporated into the soil grazing and feeding areas. Runoff from agricultural areas is a major contributor of phosphates in surface waters. Municipal wastewater is another major source of phosphate in surface water.

1.4.14 Organics

Most natural organics consist of the decay products of organic solids, while synthetic organics are usually the result of industrial wastewater discharges or agricultural runoffs.

1.4.15 Proteins

Proteins are the principal constituents of the animal origin. They occur to a lesser extent in plants. All raw animal and plant food stuffs contain proteins. Proteins are complex in chemical structure and unstable, being subjected to many forms of decomposition. Some are soluble in water and others insoluble. All proteins contain carbon along with hydrogen, nitrogen and oxygen, which is common to all organic substances. When proteins are present in large quantities extremely foul odours are produced because of their decomposition.

1.4.16 Carbohydrates

Widely distributed in nature are carbohydrates like sugars, starches, cellulose and wood fiber, all found in wastewater. Carbohydrates contain carbon, hydrogen and oxygen. Some carbohydrates, notably the sugars, are soluble in water; others such as the starches are insoluble. The sugars tend to decompose, the enzymes of certain bacteria and yeasts set up fermentation with the production of alcohol and carbondioxide. The starches, on the other hand, are more stable but are converted into sugars by microbial activity as well as by dilute mineral acids.

1.4.17 Fats, Oil and Grease

Fats and oils are the third major component of food stuffs. The term “grease” as commonly used, includes the fats, oils, waxes and other related constituents found in wastewater. Fats and oils are compounds (esters) of alcohol or glycerol with fatty acids. Fats and oils are contributed to domestic sewage in butter, vegetable fats and oils. Fats are also commonly found in meats, in seeds, in nuts and in certain fruits. Oils reach the sewer in considerable volumes from soap manufacturing units, from garages and street washes. These interfere with biological action of microbes and cause maintenance problem of sewers and treatment plants.

1.4.18 Phenols

Phenols and other trace organic compounds are also important constituents of wastewater. Phenols cause taste problems in drinking water, particularly when the water is chlorinated. They are produced primarily by industrial operations and find their way to surface waters in wastewater discharges that contain industrial wastes.

1.4.19 Pesticides and Agricultural Chemicals

Trace organic compounds, such as pesticides, herbicides and other agricultural chemical are toxic to most life forms and cause contamination of surface waters.

1.4.20 Dissolved Oxygen

The living organisms are dependent upon oxygen in one form or another to maintain the metabolic processes that produce energy for growth and reproduction. All the gases of atmosphere dissolve in water to some degree. Both nitrogen and oxygen are poorly soluble. The solubility of atmospheric oxygen in fresh waters ranges from 14.6 mg/ℓ at 0°C to about 7.6 mg/ℓ at 30°C at 1 atmospheric pressure. Dissolved salts of water reduce the solubility of oxygen so also impurities in water.

1.4.21 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is defined as the amount of oxygen required by microorganisms to stabilize decomposable organic matter at a particular time and temperature. BOD test is widely used to determine the pollutional strength of domestic and industrial wastes in terms of the oxygen that they require to deliver end products as CO_2 and H_2O. The BOD test is essentially a bioassay procedure involving the measurement of oxygen consumed by living organisms (mainly bacteria) while utilizing the organic matter present in the waste as carbohydrates, proteins and fats. It is standardized at 20°C the usual peak temperature of summer of London where the test originated. Theoretically infinite time is required for complete biological oxidation of organic matter of domestic sewage but for all practical purposes, the reaction may be considered to be completed in about (90–95%) 20 days. In case of domestic wastewaters, it has been found that the 5* day BOD value is about 70 to 80% of the ultimate (I stage – carbonaceous) BOD. This is fairly a higher percentage and hence 5 day (at 20°C) values are used for many considerations and unless otherwise mentioned BOD means only 5 day 20°C value only. Nitrifying bacteria is the bacteria which oxidize proteinous matter for energy. The nitrifying bacteria are usually pre sent in relatively small numbers in untreated domestic wastewater. Their reproductive rate at 20°C is such that their populations do not become sufficiently large to exert an appreciable demand for oxygen until about 8 to 10 days. Once the organisms become established, they oxidize nitrogen in the form of ammonia to nitrates and nitric acids in amounts that induce serious error in BOD estimation.

Estimation of BOD:

1. The most widely used parameter of organic pollution applied to both wastewater and surface water is the 5 day BOD (BOD_5) at 20°C.
2. BOD determination involves the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter.
3. The reason is that BOD test results are now used (i) to determine the approximate quantity of oxygen that will be required to biologically stabilize the organic matter present (ii) to determine the extent of waste treatment facilities (iii) to measure the efficiency of the biological treatment processes.
4. In the standard BOD test, a small sample of the wastewater to be tested is placed along with dilution water in a BOD bottle (300 mℓ). The dissolved oxygen concentration of the mixture in the bottle is measured. The bottle is incubated for 5 days at 20°C and the dissolved oxygen concentration is measured again. The BOD of the sample is the decrease in the dissolved oxygen concentration values, expressed in mg/ℓ; divided by the decimal fraction of the sample used.

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* Note: All rivers flow (from origin to the end i.e., before joining the sea) for less than 5 days in Great Britain where the BOD test originated.

Limitations of BOD test:

1. A minimum DO depletion of 2 mg/ℓ is desirable.
2. The final DO should never be 0 mg/ℓ. (as it is impossible to know when the entire DO content got fully depleted i.e., within 1, 2, 3, 4 or 5 days) and preferably it should not be less than 1 mg/ℓ.

1.4.22 Chemical Oxygen Demand (COD)

COD may be defined as the amount of (dissolved) oxygen required to oxidize and stabilize (organic and inorganic content of) the sample solution. It is used to measure the content of oxidizable organic as well as inorganic matter of the given sample of waters. The oxygen equivalent is measured by using a strong chemical oxidizing agent in an acidic medium. Potassium dichromate has been found to be excellent for this purpose. The COD test is used with advantage to measure the oxidizable matter in industrial and municipal wastes containing compounds that are toxic to biological life (which is not possible with BOD test). The COD of a waste is higher than the BOD because more compounds are chemically oxidized in a short interval of time. It had the advantage of getting completed in 3 hours compared to 5 days of the BOD test. It is possible to correlate BOD and COD. BOD_5/COD ratio is called *Biodegradability Index* and varies from 0.4 to 0.8 for domestic wastewaters.

If BOD/COD is > 0.6 then the waste is fairly biodegradable and can be effectively treated biologically.

If BOD/COD ratio is between 0.3 and 0.6, then seeding is required to treat it biologically.

If BOD/COD is < 0.3 then it cannot be treated biologically.

1.4.23 Biodegradable Organics

Biodegradable material consists of organics that can be utilized as food by microorganisms. In dissolved form, these materials usually consist of starches, fats, proteins, alcohols, acids, aldehydes and esters. They may be the end product of the initial microbial decomposition of plant or animal tissue or they may result from domestic or industrial wastewater discharges. Microbial metabolism may be by oxidation or by reduction.

In aerobic (oxygen present) environments, the end products of microbial decomposition are stable and acceptable compounds associated with oxygen as CO_2, NO_3 etc. Anaerobic (oxygen absent) decomposition results in odourous and objectionable end products as H_2S. The oxygen demanding nature of biodegradable organics represents their pollutional strength.

The amount of oxygen consumed during microbial utilization of organics is called the Biochemical Oxygen Demand (BOD). The BOD is measured by determining the oxygen consumed from a sample placed in an air tight 300 mℓ BOD bottle incubated at 20°C for 5 days.

$$\text{The BOD of a diluted sample} = \frac{DO_I - DO_F}{r}$$

Where DO_I and DO_F are the initial and final dissolved oxygen concentration (mg/ℓ) and r is the dilution ratio (a fraction).

The BOD of sanitary sewage may range from 50 to 200 mg/ℓ. A minimum of three dilutions are prepared to cover this range. The sample is placed in the standard BOD bottle and is then diluted to 300 mℓ with organic free, oxygen saturated distilled water.

Problem

The following data were obtained in a BOD test. Find the average BOD of the wastewater.

S.No.	Wastewater (mℓ)	DO_0 (mg/ℓ)	DO_5 (mg/ℓ)	O_2 used (mg/ℓ)	(Dilution ratio)	BOD_5^{20} (mg/ℓ)
1	5	9.0	6.7	2.3	5/300 = 0.0167	138
2	10	9.2	4.5	4.7	10/300 = 0.033	142
3	15	8.2	6.9	1.3	15/300 = 0.05	260
4	20	7.9	0.5	7.4	20/300 = 0.067	110

Of these values the third value cannot be accepted, as the minimum depletion of DO of 2.0 mg/ℓ is not satisfied. Therefore the third value is discarded.

For the fourth reading the final DO is less than 1.0 mg/ℓ and hence this value is also discarded. Therefore acceptable values of BOD 138 mg/ℓ and 142 mg/ℓ.

The average BOD of the wastewater is $\frac{138 + 142}{2}$ = 140 mg/ℓ

1.4.24 Mathematical Formulations of the BOD

In a BOD test, the rate at which organics are utilized by microorganisms is assumed to be a first order reaction. The rate at which organics utilized is proportional to the amount of oxidizable organic matter available at that time and temperature.

Mathematically, this can be expressed as follows:

Rate of deoxygenation is proportional to organic matter still present (to get oxidized) $\frac{dL}{dt} = -k^1 L$

where L is the organic matter remaining to get oxidized at a time t, and k^1 is a deoxygenation constant (at 20°C ≈ 0.1 per day.)

$$\frac{dL}{L} = -k^1\, dt$$

Taking integrals on both sides

$$\int_{L}^{L_t} \frac{dL}{L} = -k^1 \int_0^t dt$$

$$\log_e \frac{L_t}{L_o} = -k^1 t$$

$$L_t = L_o e^{-k^1 t} \text{ or } L_t = L_o\, 10^{-kt}$$

The term L_0 in this equation represents the total oxygen equivalent to the organics at time = o, while L_t represents the amount remaining at time = t (decays exponentially). The oxygen equivalent remaining is not the parameter of primary importance. However, the amount of oxygen used in the consumption of the organics, the BOD_t, can be found from the L_t value.

If L_o is the oxygen equivalent of the total mass of organics, then the difference between the value L_o and L_t is the oxygen equivalent consumed or the BOD exerted.

BOD exerted = Ultimate BOD – BOD remaining at that time

$$y_t = L_o - L_t = L_o - L_o e^{-k^1 t} = L_o(1 - e^{-k^1 t}) = L_o(1 - 10^{-kt})$$

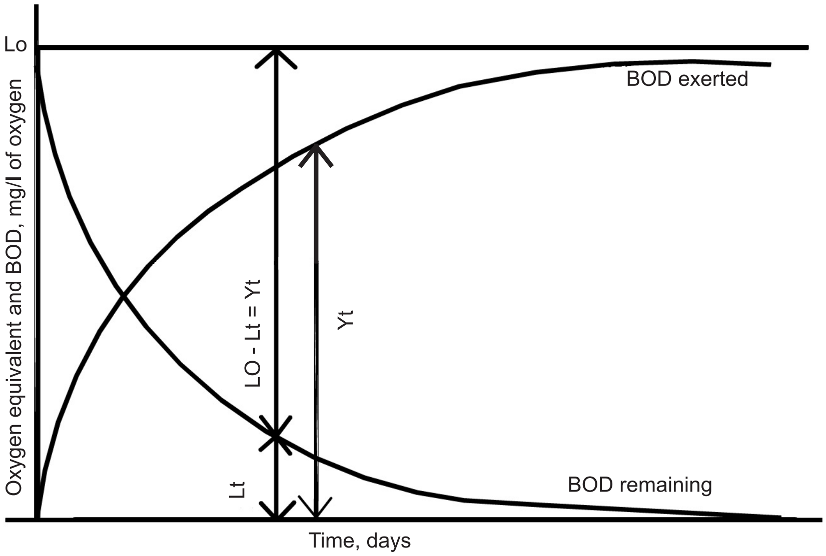


Fig. 1.3: BOD and oxygen equivalent relationships

where y_t represents the BOD_t of the wastewater

The deoxygenation constant (k^1 or k) is not exactly a constant but varies with temperature.

Deoxygenation constant at a temperature T,

$$k_T = k_{20}\ (1.047)^{T-20}$$

Similarly Ultimate BOD or Initial Oxygen Equivalent L_o also varies with temperature.

$$[L_o]_T = [L_o]_{20}\ (0.02T + 0.6)$$

Problems

1. If the 3 day, 20°C BOD of a sample is 300 mg/ℓ, what is its ultimate BOD?

   3 day BOD at 20°C, $y_t = 300$ mg/ℓ

   $y_t = L_o (1 - 10^{-kt})$

   where $y_t = 300$ mg/ℓ, $t = 3$ days and $k_{20} = 0.1$/day

   $300 = L_o (1 - 10^{-0.1 \times 3})$

   $L_o = 601.428$ mg/ℓ

2. If the 5 day BOD at 37°C is 200 mg/ℓ and if the rate of deoxygenation is 0.17/day, what is the ultimate BOD and BOD remaining after 5 days?

   5 day BOD at 37ºC, $y_t = 200$ mg/ℓ

   $y_t = L_o (1 - 10^{-kt})$

   where $y_t = 200$ mg/ℓ, $t = 5$ days and $k_{20} = 0.17$/day

   $200 = L_o (1 - 10^{-0.17 \times 5})$

   $L_o = 232.9$ mg/ℓ

   Ultimate BOD = 232.9 mg/ℓ.

   BOD remaining at any time t, $L_t = L_o (10^{-kt})$

   $L_t = 232.9 (10^{-0.17 \times 5}) = 32.9$ mg/ℓ

BOD remaining after 5 days = 32.9 mg/ℓ.

Or

$y_t = L_o - L_t$

$200 = 232.9 - L_t$

$L_t = 32.9$ mg/ℓ

3. If the 5 day BOD of a sample is 276 mg/ℓ and ultimate BOD at the same temperature is 380 mg/ℓ, at what rate the waste is oxidized?

5 day BOD, $y_t = 276$ mg/ℓ

Ultimate BOD (L_o) = 380 mg/ℓ

$y_t = L_o\,(1 - 10^{-kt})$

where $y_t = 276$ mg/ℓ, $t = 5$ days and k_T =?

$276 = 380\,(1 - 10^{-k \times 5})$

$1 - 10^{-k \times 5} = 276/380 = 0.726$

$10^{-5k} = 0.2736$

$10^{5k} = 3.6538$

$5k = \log_{10}(3.6538)$

$5k = 0.56275$

$k = 0.1125$/day

4. If the 3 day BOD at 15°C = 425 mg/ℓ, what will be its 7 day BOD at 15°C?

3 day BOD (y_t) at 15°C = 425 mg/ℓ

Assume $k^1 = 0.23$/day

$k^1{}_{15} = k^1{}_{20}\,(1.047)^{T-20}$

$k^1{}_{15} = (0.23)(1.047^{15-20}) = 0.182$/day

$y_t = L_o\,(1 - e^{-kt)}$

where $y_t = 425$ mg/ℓ, $k^1 = 0.182$/day and $t = 3$ days

$425 = L_o\,(1 - e^{-0.182 \times 3})$

$425 = L_o\,(1 - 0.579)$

$[L_o]$ at 15°C = 1010.13 mg/ℓ

$y_t = L_o\,(1 - e^{-k.t})$

$y_7 = 1010.13\,(1 - e^{-0.182 \times 7})$

7 day BOD at 15°C (y_7) = 727.585 mg/ℓ

5. If the 3 day, 15°C BOD is 200 mg/ℓ, what will be its 7 day BOD at 25°C?

3 day BOD (y_t) at 15°C = 200 mg/ℓ

7 day BOD (y_t) at 25°C = ?

Assume $k = 0.1$/day

$k_{15} = k_{20}\,(1.047)^{T-20} = (0.1)(1.047^{15-20}) = 0.07948$/day

$k_{25} = (0.1)(1.047^{25-20}) = 0.1258/\text{day}$

$y_t = L_o(1 - 10^{-kt})$

where $y_t = 200\ \text{mg}/\ell$, $k = 0.07948/\text{day}$ and $t = 3$ days

$200 = L_o\ (1 - 10^{-0.07948 \times 3})$

$200 = L_o\ (1 - 0.5775)$

$[L_o]$ at 15°C = 473.384 mg/ℓ

$[L_o]_T = [L_o]_{20}\ (0.02T + 0.6)$

$T = 15°\text{C}$

$[L_o]_{15} = [L_o]_{20}\ (0.02 \times 15 + 0.6)$

$474.384 = [L_o]_{20}\ (0.9)$

$[L_o]_{20} = 527.09\ \text{mg}/\ell$

$[\text{L}_\text{o}]_\text{T} = [\text{L}_\text{o}]_{20}\ (0.02\text{T} + 0.6)$

where $T = 25°\text{C}$

$[L_o]_{25} = [L_o]_{20}\ (0.02 \times 25 + 0.6)$

$[L_o]_{25} = 527.09\ (1.1) = 579.8\ \text{mg}/\ell$

$y_t = L_o(1 - 10^{-kt})$

where $[L_o]_{25} = 579.8\ \text{mg}/\ell$ and $k_{25} = 0.1258/\text{day}$

y_7 at 25°C = $[L_o]_{25}\ (1 - 10^{-kt})$

y_7 at 25°C = $579.8\ (1 - 10^{-0.1258 \times 7}) = 579.8\ (0.8683)$

7 day BOD at 15°C (y_7) = 503.47 mg/ℓ

Non-biodegradable organics: Some organic materials are resistant to biological treatment. Tannic and lignin acids, cellulose and phenols are often found in natural water systems. Measurement of non-biodegradable organics is usually done by the chemical oxygen demand (COD) test. Non-biodegradable organics may also be estimated from a total organic carbon (TOC) analysis. Both COD and TOC measure the biodegradable fraction of the organics, so the BOD_u must be subtracted from the COD or TOC to quantify the non-biodegradable organics (Refractories).

1.5 BIOLOGICAL CHARACTERISTICS

The principal groups of microscopic flora and fauna found in surface water and wastewater are classified as *protists* which mainly comprise Bacteria (plants), Algae (plants), Fungi (plants) and protozoa (animals). Rotifers and worms to macroscopic crustaceans are the others. Pathogenic organisms found in wastewater may be discharged by human beings who are infected with disease or who are carriers of a particular disease.

From the perspective of human use and consumption, the most important biological organisms in water are pathogens capable of infecting, or of transmitting diseases to humans. These organisms are not native to aquatic systems and usually require an animal host for growth and reproduction. They can however be transported by natural water systems, thus becoming a temporary member of the aquatic community. Many species of pathogens are able to survive in water and maintain their infectious capabilities for significant periods of time. These waterborne pathogens include species of bacteria, viruses, protozoa and helminthes (parasitic worms).

1.5.1 Bacteria

The word bacteria comes from the Greek word meaning “rod” or “staff” a shape characteristic of most bacteria. Bacteria are single cell microorganisms, usually colourless and are the lowest form of plant life capable of synthesizing protoplasm from the surrounding environment. In addition to the rod shape (*bacilli*), bacteria may also be spherical (*cocci*), comma shaped (*vibrio*), or spiral shaped (*spirilla*). Gastrointestinal disorders are common symptoms of most diseases transmitted by waterborne pathogenic bacteria.

1.5.2 Viruses

Viruses are the smallest biological structure known to contain all the genetic information necessary for their own reproduction. It is the demarcation between living and non-living objects. Viruses require a host to live and to multiply. Waterborne viral infection usually involves disorders of the nervous system rather than those of the gastrointestinal tract. Waterborne viral pathogens are *Poliomyelitis* (Polio) and *infectious hepatitis* (yellow jaundice).

1.5.3 Protozoa

The lowest form of animal life, protozoa, are unicellular organisms more complex in their functional activity than bacteria or viruses. Protozoal infections are usually characterized by gastrointestinal disorders as amoebic dysentery.

Table 1.2: Important pollutants in wastewater

S.No.	*Pollutants*	*Significance*
1.	Suspended solids	Development of sludge deposits and anaerobic conditions.
2.	Organics (Biodegradable)	Principally carbohydrates, proteins and fats-starving products (contribute BOD).
3.	Refractory organics (Non-biodegradable)	Principally phenols, agricultural fertilizers and pesticides – cannot be removed by conventional wastewater treatment techniques, may harm biological community and hence biological treatment may be hampered.
4.	Pathogens	Waterborne diseases (cholera, typhoid, dysentery) are transmitted by the pathogenic organisms in wastewater.
5.	Nutrients	Phosphates and Nitrates contribute to *Eutrophication* of static water bodies as lakes and ponds.
6.	Dissolved inorganic solids	Excess salts of sodium and calcium etc. are to be removed to render the water fit for domestic and industrial use.
7.	Heavy metals	Nickel, Manganese, Lead, Chromium, Cadmium, Zinc, Copper, Iron and Mercury in higher concentrations are detrimental for aquatic life.

1.6 DISPOSAL OF WASTEWATER

Methods of disposal:

(i) Natural Methods: Disposal by Dilution
(ii) Artificial Methods: Primary & Secondary Treatment.

1.6.1 Disposal by Dilution

Disposal by dilution is the process whereby the treated wastewater or effluent from treatment plants is discharged either in large static water bodies (such as lake or sea) or in moving water bodies such as rivers or streams. The discharged wastewater or effluent is purified, in due course of time by the so-called Self-purification Process of Natural Waters.

After conveying the wastewater through sewers, it is disposed of, either after complete treatment, primary treatment or even without any treatment. Before being discharged into natural streams the wastewater preferably should satisfy the following criteria:

i. Suspended solids ($\ngtr 50$ mg/ℓ)
ii. BOD ($\ngtr 150$ mg/ℓ)
iii. Free from oils and greases and should be free from bigger settleable solids.

The stream should satisfy the following requirements:

i. The flow $\nless 110$ ℓ/s/1000 people.
ii. It is saturated with DO to prevent fish kills.

After discharge by dilution the combined flow should have a minimum dissolved oxygen of 3 mg/ℓ any time thereafter.

$$\text{Minimum dilution ratios} = \frac{\text{Quantity of fresh water flow of the river}}{\text{Quantity of sewage discharged}}$$

Table 1.3: Dilution ratios

Dilution ratio	*Characteristics of wastewater before dilution*
> 500 times	Sewage with no treatment
300 – 500	Suspended solids < 150 mg/ℓ Preliminary treatment is a must
150 – 300	Suspended solids < 60 mg/ℓ

1.7 SELF-PURIFICATION OF NATURAL STREAMS

When the wastewater or the effluent is discharged into a natural stream, the organic matter is converted into ammonia, nitrates, sulphates, carbon dioxide etc. by bacteria. In this process of oxidation, the dissolved oxygen content of natural water is utilized. Due to this, deficiency of dissolved oxygen is created.

As the excess organic matter is stabilized, the normal cycle will be in a process known as Self-purification wherein the dissolved oxygen is replenished by its reaeration by atmospheric oxygen of wind.

Actions Involved in Self-purification:

1. *Dilution:* When wastewater is discharged into the receiving water, dilution takes place due to which the concentration of organic matter is reduced and the potential nuisance of sewage is also reduced. When the dilution ratio is quite high, large quantities of DO are available which will accelerate the chances of purification and reduce pollution effects. Aerobic condition will always exist because of higher dilution. This will however, not be there if dilution ratio is small, i.e., when large quantities of oxygen demanding effluent is discharged into a small stream supplementing little oxygen or aeration.

2. *Dispersion due to Currents:* Self-purification of stream largely depends upon currents, (as rapids, whirlpools, waterfalls and turbulent flow) which will readily disperse the wastewater in the stream, preventing local accumulation of pollutants.
   High velocity accelerates reaeration and reduces the concentration of pollutants. High velocity improves reaeration, reduces the time of recovery, though length of stream affected by the wastewater is increased.
3. *Sedimentation:* If the stream velocity is lesser than the scour velocity of particles, sedimentation will take place, which will have two effects.
   (i) The suspended solids, which contribute largely the oxygen demand, will be removed by settling and hence water quality of the downstream is improved.
   (ii) Due to settled solids, *Anaerobic* decomposition may take place.
4. *Temperature:* At low temperature, the activities of bacteria is low and hence rate of decomposition will also be slow, though DO will be more because of increased solubility of oxygen in water. At high temperatures, the self-purification takes lesser time, though the quantity of DO will be less.
5. *Sunlight:* Sunlight helps *photosynthesis* of certain aquatic plants (as algae) to absorb carbon dioxide and give out oxygen, thus accelerating self-purification. Sunlight acts as a *disinfectant.*

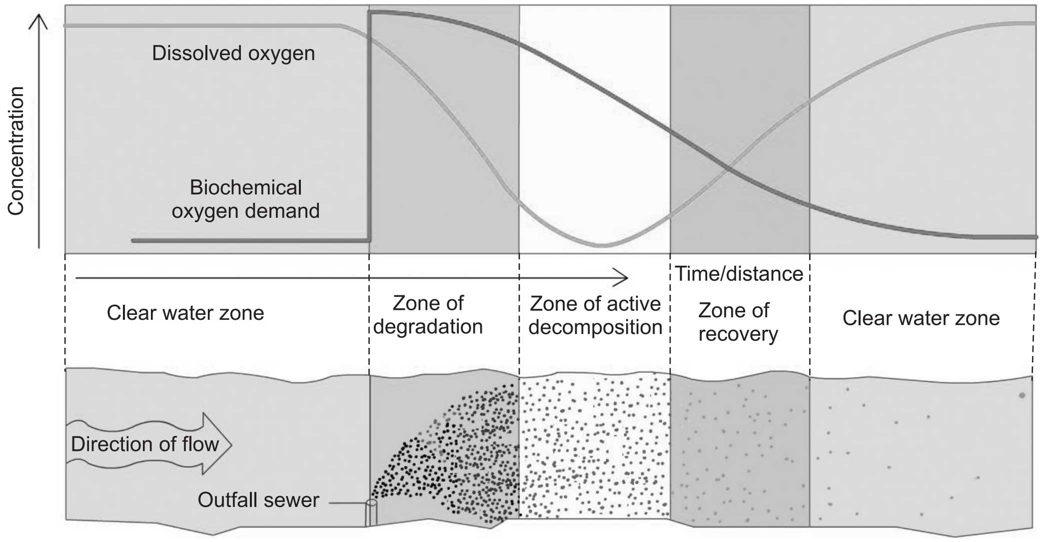


Fig. 1.4: Zones of pollution in streams (Oxygen sag analysis)

Zones of Pollution in the Streams: The Self-purification process of a stream polluted by the wastewater or effluent discharged into it can be divided into the following four zones:

(i) Zone of Degradation (Decomposition zone)
(ii) Zone of Active Decomposition (Septic zone)
(iii) Zone of Recovery
(iv) Zone of Clear Water

Zone of Degradation: This zone is situated just below the outfall sewer while discharging its contents into the stream. In this zone, water is rendered dark and turbid, having the formation of sludge deposits at the bottom. The DO is reduced to 40% of the saturation values. There is an increase in CO_2 content, and *reaeration* is much slower than *deoxygenation*. (Though conditions are unfavourable for aquatic life, fungi at shallow depths and bacteria at greater depths breed along with small worms, which 'work over' and stabilize the sewage and sludge). The decomposition of solid matter takes place in this zone and anaerobic decomposition prevails over aerobic decomposition.

Zone of Active Decomposition: This zone is just the continuation of degradation zone and is marked by heavy pollution. Water in this zone becomes grayish and darker than the previous zone. The DO concentration in this zone falls down to zero. Active anaerobic organic decomposition takes place, with the evolution of Methane (CH_4), Hydrogen sulfide (H_2S), Carbon dioxide (CO_2) and Nitrogen (N_2) bubbling to the surface with masses of sludge forming black scum. Fish life is absent in this zone but bacterial flora will flourish with the presence of anaerobic bacteria at upper end and aerobic bacteria at the lower end. However, near the end of this zone, as the decomposition slackens, reaeration sets in and DO again rises to its original level of 40% (of saturation value).

Zone of Recovery: In this zone, the process of recovery starts, from its degraded condition to its former purer condition. The stabilization of organic matter takes place in this zone. Due to this, most of the stabilized organic matter settles as sludge, BOD falls and DO content rises above 90% value. Near the end of the zone, fungi wave out and algae reappear.

Clear Water Zone: In this zone, the natural condition of stream is restored with the result that

(i) Water becomes clearer and attractive in appearance.
(ii) DO rises to the saturation level, and BOD drops to the lowest value.
(iii) Oxygen balance is attained.

1.8 OXYGEN SAG ANALYSIS

The oxygen sag or oxygen deficit in the stream at any point of time during the self-purification process is the difference between the saturation DO content and the actual DO content at that time.

The normal saturation DO value for fresh water depends upon the temperature, and its value varies from 14.62 mg/ℓ at 0°C to 7.63 mg/ℓ at 30°C. (at normal atmospheric pressure).

At the point where wastewater is discharged into the stream, the DO content of the stream may be equal to the saturation DO or less. If less, it is termed as initial oxygen deficit D_o.

$$D_o = \text{Saturated DO} - \text{Actual DO}$$

At this stage, when the wastewater with an initial BOD load L_o is discharged into the stream, the DO content of the stream starts depleting and the oxygen deficit D increases initially. The variation of oxygen deficit D along the length of the stream is depicted by the Oxygen Sag Curve as shown in Fig 1.4 .

The major point of interest in the oxygen sag analysis is the point of minimum DO or the point of maximum deficit. The maximum or critical deficit, labeled as D_c occurs at the inflection point of the oxygen sag curve (DO content increase thereafter).

Deoxygenation and Reaeration Curves

When the wastewater (pollution load) is discharged into the stream, the DO content of the stream goes on depleting. This depletion of DO content is known as *deoxygenation*. The rate of deoxygenation depends upon the amount of organic matter remaining (L_t) to be oxidized at any time (t), as well as temperature (T) of the reaction. The variation or depletion of DO content of the stream *versus* time is depicted by the Deoxygenation curve in the absence of aeration. The ordinates below the Deoxygenation curve indicate the oxygen still remaining in the natural stream.

Though the DO content of the stream is gradually consumed due to the pollutional (BOD) load, atmosphere supplies oxygen continuously to the water through the process of reaeration. In other words, along with deoxygenation, reaeration also continuously takes place.

The rate of *Reaeration* depends upon

(i) depth of water in the stream (rate is more at shallow depths)
(ii) velocity of flow in the stream (rate is more for more velocity)
(iii) oxygen deficit below saturation DO (more the deficit rapid is the rate of reaeration)
(iv) temperature of water.

Deoxygenation in Rivers

The DO in rivers and streams is depleted by the bacterial oxidation of the suspended and dissolved organic matter discharged to them by both natural and man-made sources and by the oxygen demand of sludge and benthic deposits.

Reaeration in Rivers

The sources of oxygen replenishment in a river are reaeration from the atmosphere and photosynthesis of aquatic plants as algae. The amount of reaeration is proportional to the dissolved oxygen deficiency. The amount of oxygen supplied by photosynthesis is a function of the size of the algal population and the amount of sunlight reaching the algae.

Oxygen Sag curve in a polluted stream is given by Streeter and Phelp's equation:

$$D_t = \frac{kL_o}{k_2 - k}[10^{-kt} - 10^{-k_2t}] + D_o 10^{-k_2t}$$

DO deficit (D_t) = saturated DO – actual DO (mg/ℓ)

D_t = DO deficit in the stream after time t from the instant of pollution or at distance $x = ut$

L_o = initial BOD of stream at $t = 0$ (mg/ℓ)

D_o = initial DO deficit at $t = 0$ (mg/ℓ)

k = BOD reaction rate constant (Deoxygenation constant) (per day)

k_2 = DO deficit reduction rate constant (Reoxygenation constant) (per day)

u = mean velocity of the stream (m/d)

t = time (day)

Critical oxygen deficit and time can be calculated by

$$D_C = \frac{k}{k_2} L_o 10^{-k\,t_c}$$

$$t_C = \frac{1}{k_2 - k} \text{In}\left[\frac{k_2}{k}\left(1 - \frac{D_o(k_2 - k)}{k\,L_o}\right)\right]$$

Problem

A wastewater of 5.0 m^3/sec is discharged into a river of flow 50 m^3/sec. The ultimate BOD of wastewater is 200 mg/ℓ and DO is 1.5 mg/ℓ. The river water has a BOD of 3 mg/ℓ and DO of 7 mg/ℓ. The reaeration coefficient of the river water is 0.2/day and BOD decay coefficient is 0.4/day. The river has a cross-sectional area of 200 m^2 and the saturated DO concentration of the river water is 8 mg/ℓ.

(a) At a downstream point of 10 km calculate the DO of the mixture.

(b) At which point the DO is a bare minimum.

Given

Flow rate of river water = 50 m^3/sec

Wastewater flow rate = 5 m^3/sec

BOD of river water = 3 mg/ℓ

BOD of wastewater = 200 mg/ℓ

$$\text{BOD of the mixture} = \frac{(50)(3)+(5)(200)}{50+5} = 20.91 \text{ mg}/\ell$$

DO of the river water = 7 mg/ℓ

DO of the wastewater = 1.5 mg/ℓ

$$\text{DO of the mixture} = \frac{(50)(7)+(5)(1.5)}{50+5} = 6.5 \text{ mg}/\ell$$

Initial oxygen deficit = Saturated DO – Initial DO of the mixture

$D_o = 8.0 - 6.5 = 1.5$ mg/ℓ

$$\text{Velocity of flow} = \frac{\text{Rate of flow}}{\text{Area of cross-section}} = \frac{50+5}{200} = 0.275 \text{ m/s}$$

Length of flow = 10 km = 10000 m

$$\text{Time} = \frac{\text{Distance}}{\text{Velocity}} = \frac{10000}{0.275} = 36363.63\ s = 0.42\ d$$

Deoxygenation constant (k) = 0.4 /day

Reaeration constant (k_2) = 0.2 /day

Oxygen Sag curve in a polluted stream is given by Streeter and Phelp’s equation:

$$D_t = \frac{kL_o}{k_2 - k}[10^{-kt} - 10^{-k_2t}] + D_o 10^{-k_2t}$$

$$D_t = \frac{(0.4)(20.91)}{(0.2-0.4)}\left[10^{-(0.4)(0.42)} - 10^{-(0.2)(0.42)}\right] + (1.5)(10^{-(0.2)(0.42)})$$

$$D_t = \frac{8.364}{-0.2}[0.6792 - 0.8241] + (1.5)(0.8241)$$

D_t = 7.289 mg/ℓ

$$t_C = \frac{1}{k_2 - k} \text{In}\left[\frac{k_2}{k}\left(1 - \frac{D_o(k_2 - k)}{k\,L_o}\right)\right]$$

$$t_C = \frac{1}{0.2 - 0.4} \text{In}\left[\frac{0.2}{0.4}\left(1 - \frac{(1.5)(0.2 - 0.4)}{(0.4)(20.91)}\right)\right]$$

$$t_C = (-5)\ \text{In}\left[0.5\left(1 - \frac{(-0.3)}{8.364}\right)\right]$$

t_C = (–5) In[0.5)(1.0358)]

t_C = (–5) (–0.65797) = 3.289 days

Distance = Velocity × t_c = (0.275 × 3.289 × 60 × 60 × 24)/(1000) = 78.15 km

Problem

A city discharges 1.25 m^3/s of wastewater into a stream whose minimum rate of flow is 8.0 m^3/s. The velocity of the stream is about 3.0 km/h. The temperature of the wastewater is 20°C and that of the stream is 15°C. The 20°C BOD_5 of the wastewater is 250 mg/ℓ and that of the stream is 2 mg/ℓ. The wastewater contains no dissolved oxygen, but the stream is flowing with saturated DO concentration of 9.2 mg/ℓ. Saturated DO at 15°C is 10.2 mg/ℓ. At 20°C, deoxygenation constant (k^1) is estimated to be 0.3 per day and reaeration constant (k_2^1) is 0.7 per day. Determine the critical oxygen deficit and its location. Also estimate the 20°C BOD_5 of a sample taken at the critical point. Use the temperature coefficients of 1.135 for k^1 and 1.024 for k_2^1.

Given

Flow rate of river water = 8 m^3/sec

Wastewater flow rate = 1.25 m^3/sec

BOD of river water = 2 mg/ℓ

BOD of wastewater = 250 mg/ℓ

$$\text{BOD of the mixture} = \frac{(8)(2) + (1.25)(250)}{8 + 1.25} = 35.51 \text{ mg/ℓ}$$

DO of the river water = 9.2 mg/ℓ

DO of the wastewater = 0.0 mg/ℓ

$$\text{DO of the mixture} = \frac{(8)(9.2) + (1.25)(0)}{8 + 1.25} = 7.95 \text{ mg/ℓ}$$

$$L_o \text{ of the mixture} = \frac{35.51}{1 - e^{-(0.3)(5)}} = \frac{35.51}{1 - 0.223} = 45.71 \text{ mg/ℓ}$$

Initial oxygen deficit = Saturated DO – Initial DO of the mixture

D_o = 10.2 – 7.95 = 2.25 mg/ℓ

Temperature of the river water = 15°C

Temperature of the wastewater = 20°C

Temperature of the mixture = $\dfrac{(8)(15)+(1.25)(20)}{8+1.25}$ = 15.7°C

Correct the rate constants to 15.7°C

Deoxygenation constant (k^1) at 20°C = 0.3/day

Temperature coefficient for k^1 = 1.135

$k^1 = (0.3)(1.135)^{15.7-20} = 0.174$/day

Reaeration constant (k_2^1) at 20°C = 0.7/day

Temperature coefficient for k_2^1 = 1.024

$k_2^1 = (0.7)(1.024)^{15.7-20} = 0.63$/day

$$t_C = \frac{1}{k_2^1 - k^1}\,\text{In}\left[\frac{k_2^1}{k^1}\left(1 - \frac{D_o\left(k_2^1 - k^1\right)}{k^1 L_o}\right)\right]$$

$$t_C = \frac{1}{0.63-0.174}\ln\left[\frac{0.63}{0.174}\left(1-\frac{2.25(0.63-0.174)}{0.174(45.71)}\right)\right]$$

$$t_C = \frac{1}{0.456}\ln\left[3.62\left(1-\frac{2.25(0.456)}{7.953}\right)\right]$$

t_C = (2.193) ln [3.62(1 – 0.129)]

t_C = (2.193) ln (3.15302) = (2.193)(1.148) = 2.52 d

Distance $x_c = vt_c$ = (3.0 km/h)(24h/d)(2.52 d) = 181.44 km

Oxygen deficit at $x_c = D_c = \dfrac{k^1}{k_2^1} L_o e^{-k^1 t_c}$

$$D_c = \frac{0.174}{0.63}(45.71)\left(e^{-(0.174)(2.52)}\right)$$

$D_c = (12.624)(e^{-0.43848})$ = 8.142 mg/ℓ

Dissolved oxygen in stream at x_c = 10.2 – 8.142 = 2.058 mg/ℓ

Depending on the purity of its running water the streams are classified as follows:

Table 1.4: Classification of streams

Class	*Standard*	*Use*
A	without filtration < 50 B.coli/100 mℓ	Drinking water after chlorination
B	No visible sewage matter < 100 B.coli/100 mℓ	Bathing, Recreation and shellfish culture
C	DO $\nless$ mg/ℓ & preferable $\nless$ 5 mg/ℓ CO_2 (20 – 40 mg/ℓ)	Fishing
D	Absence of nuisance, odours, unsighty suspended solids, some DO present	Rough industrial use and irrigation

Discussion: Topics and Problems

1. Differentiate between “sewage” and “sewerage”.
2. Define wholesomeness of water.
3. Define BOD.
4. Name any four water-borne diseases.
5. Give an account of physical and chemical properties of wastewater.
6. Why BOD content of the untreated wastewater is high?
7. Explain why BOD test is to be conducted for wastewaters.
8. In which case DO is more – sea water or fresh water?
9. Why the BOD test is done for 5 days at 20°C?
10. What are the zones of self-purification of streams?
11. Differentiate between a BOD test and a COD test. Can a COD test be used as a substitute for a BOD test? Justify your answer.
12. Write the advantages and limitations of BOD and COD tests.
13. Derive an expression for first stage BOD exertion. Why COD values are always higher than BOD values?
14. Comment on the treatability of waste whose COD is 35,000 ppm and BOD is 25,000 ppm.
15. If 3 mℓ of raw sewage has been diluted to 300 mℓ and the DO concentration of the diluted sample at the beginning of the BOD test was 8 mg/ℓ and 5 mg/ℓ after 5 day incubation at 20°C, find the BOD of raw sewage.
16. A sewage sample is found to have a BOD_5 of 250 mg/ℓ. If the rate constant is 0.15/d, estimate ultimate carbonaceous BOD of sewage.
17. Calculate BOD of sewage sample if the initial DO, final DO and dilution percentage are 10 mg/ℓ, 2 mg/ℓ and 1% respectively.
18. The following observations were made in the laboratory on 4% dilution of wastewater sample at 20°C. Calculate the 5 day BOD at 20°C of the sample and also the ultimate first stage BOD.

    DO of the aeration dilution water = 10 mg/ℓ

    DO of the original sample of wastewater = 1 mg/ℓ

    DO of the diluted sample after 5 days incubation at 20°C = 2 mg/ℓ

    Assume K_D = 0.1 per day

19. What is the ratio of 2.5 day 35°C BOD to the 5 day 20°C BOD?
20. A sample of sewage has 4-day 20°C BOD value of 60% of the final. Find the rate constant per day.
21. The one-day and two-day BOD values of a sewage sample are 90 mg/ℓ and 115 mg/ℓ respectively at 20°C. Calculate the five-day BOD at 30°C.
22. If the 3-day, 12°C BOD is 120 mg/ℓ, what will be its 7-day, 25°C BOD?
23. A sample of water from a stream is filled in a standard 300 mℓ BOD bottle and is found to have a DO of 14 mg/ℓ. After 5 day of incubation at 20°C, the DO in the bottle dropped to 6 mg/ℓ. What is the BOD_5 of stream? Comment on quality of water.
24. In a BOD test, the samples gave the following readings:

Sample	*Initial DO (mg/ℓ)*	*DO after 5 days of incubation*
P	7.8	6.6
Q	7.8	4.0
R	7.8	0.5

If the dilution ratio is 50, find the exact BOD of the sample.

25. The following results were obtained during a BOD test, when three samples A, B and C are taken of different dilutions. Find the average BOD of the wastewater.

Sample	*Waste water*	*Initial DO*	*Final DO*
A	5 mℓ	9.2	8.9
B	10 mℓ	9.1	4.7
C	15 mℓ	8.9	0.5

26. If a river water has a BOD of 5 mg/ℓ and the flow is 2000 litres per second, containing 6 mg/ℓ of dissolved oxygen, what will be the volume of an industrial effluent containing 300 mg/ℓ BOD, to be mixed so that the river water BOD does not increase beyond 10 mg/ℓ?
27. Sketch DO sag curve and describe the salient features.
28. Write the basic Streeter – Phelps equation to describe and predict the behaviour of polluted stream. From this equation, determine critical travel time and critical deficit.
29. The BOD_L in a stream is 3 mg/ℓ and the DO is 9 mg/ℓ. Stream flow is 15 MLD. A treated sewage effluent with BOD_L 50 mg/ℓ is discharged into the stream at a rate of 5 MLD. The DO of the sewage effluent is 2 mg/ℓ. Assume the deoxygenation and reaeration constants as 0.2/day and 0.5/day respectively and the saturated DO level is 11 mg/ℓ, determine the minimum DO level in the stream. If stream velocity is 1.5 m/s, where does the minimum DO occurs.
30. Explain the importance of the following operations in BOD test
    i. pH adjustment
    ii. Seeding wastewater
    iii. Incubation at controlled temperature.

2

Treatment of Wastewater

2.1 WATER POLLUTION CONTROL

Water pollution control basically involves two sets of measures (i) Preventive measures, and (ii) Curative measures. The preventive steps are:

a. Volume reduction of waste water
b. Strength reduction

2.1.1 Volume Reduction

Volume reduction can be achieved by

i. Classifications of wastes: Concentrated wastewaters of manufacturing process are segregated from dilute wastes as cooling waters, thereby reducing the intensive treatment required.
ii. Conservation of waste water.
iii. Improved process control, improved equipment design and use of different or better quality raw materials etc.
iv. Re-using both treated industrial and municipal effluents as raw water supplies.
v. Elimination of batch or slug discharges of process wastes.(If the waste is discharged in a short period of time, it is usually referred to as a slug discharge.) This type of waste, because of its concentrated contaminants surge in volume can be troublesome to both treatment plants and receiving streams.

2.1.2 Strength Reduction

Strength reduction can be achieved by

i. Process changes: industry can modify manufacturing process so that fewer wastes are created.
ii. Equipment modifications: changes in equipment can affect a reduction in the strength of the waste, usually by reducing the amounts of contaminants entering the waste stream.
iii. Segregation of wastes reduces the strength eliminating the difficulty of treating the final waste from an industrial plant. It usually results in two types of wastes, one strong but smaller in volume and the other weaker of almost the same volume as the original unsegregated waste. The strong waste can then be handled easily with specific methods as their quantity is less.
iv. Equalization of wastes: Blending of cool and hot wastes, acids and alkalies, strong waste and dilute waste nullifies or minimizes their pollutional characteristics and renders them stable. Stable effluents are treated more easily and efficiently, than unstable ones.

v. By-product recovery: Almost all the wastes contain by products. Recovery and use of these byproducts reduce the total pollutional strength of the waste. For example flyash produced from thermal power plants can be used to manufacture bricks, cement etc.
vi. Proportioning of wastes.
vii. Monitoring waste streams: Accidental spills and controlling malfunctioning of treatment plants.

The preventive measures outlined above are general and one or more of them may be applied, depending on the specific case.

2.2 NEUTRALIZATION

Excessively acidic or alkaline wastes should not be discharged without treatment into a receiving stream. A stream is adversely affected by the discharge of wastewaters of low or high pH values. Neutralization is reducing the impact of acids or alkalis by mixing them with each other.

Acceptable Methods of Neutralization

1. Mixing of different wastes of different polarities and concentrations so that the net effect is a neutral pH.
2. Passing acid wastes through beds of limestone.
3. Mixing acid wastes with lime slurries.
4. Adding the proper proportions of concentrated solutions of caustic soda(NaOH) or soda ash (Na_2CO_3) to acid wastes.
5. Passing compressed CO_2 through alkaline wastes.
6. Adding sulphuric acid to alkaline wastes.

The volume, kind and quality of acid or alkali to be neutralized are also factors in deciding which neutralizing agent is to be used.

2.3 EQUALIZATION

Equalization is a method of intermixing by retaining wastes in a basin so that the effluent discharged is fairly uniform in its characteristics (pH, colour, turbidity, alkalinity, B.O.D etc). A secondary but significant effect of equalization is lowering of the concentration of effluent contaminants. A common retention pond serves to level out the effects of peak loadings on the plant while substantially lowering the B.O.D and suspended solids load to the aeration unit.

Air is sometimes injected into these basins to provide:

1. Better mixing
2. Chemical oxidation of reduced compounds
3. Some degree of biological oxidation
4. Agitation to prevent suspended solids from settling.

The capacity of the pond should be adequate to hold and intimately mix all the wastes from the plant to form a stable homogeneous mix throughout. Thus each unit volume of waste discharged must be adequately mixed with other unit volumes of waste discharged many hours previously.

This mixing may be brought about in the following ways:

i. Proper distribution and baffling

ii. Mechanical agitation
iii. Aeration, and
iv. Combination of all three.

2.4 PROPORTIONING

Proportioning is the discharge of industrial wastes in proportion to the flow of municipal sewage in the sewers or to the stream flow in the receiving river. In most cases it is possible to combine equalization and proportion in the same basin. The effluent from the equalization basin is metered into the sewer or stream according to a predetermined schedule. The objective of proportioning in sewers is to keep constant the percentage of industrial wastes to domestic sewage flow entering the municipal sewage plant.

This procedure has several purposes:

i. To protect municipal sewage treatment from being impaired by a sudden overdose of chemicals contained in the industrial waste.
ii. To protect biological treatment devices from strong loads of industrial wastes, which may inactivate the bacteria.
iii. To minimize fluctuations of sanitary standards in the treated effluent.

The rate of flow of industrial waste varies from instant to instant, as does the flow of domestic sewage system. Therefore the industrial waste must be equalized and retained, then proportioned to the sewer or stream according to the volume of domestic sewage or stream flow.

2.5 WASTEWATER TREATMENT

Treatment is the process of removal of undesirable constituents of the wastewater to render it (i) flow freely and rapidly, (ii) free from nuisance causing matter and (iii) to stabilize its constituents.

The object of wastewater treatment is to stabilize decomposable organic matter present in the wastewater so as to produce an effluent (supernatant) and sludge (bottom sediment) which can be disposed of into the environment without causing any health hazard or nuisance.

Curative measures deal with the actual treatment of liquid effluents by physical, chemical and biological methods, or their combinations, depending on the nature of the pollutants in the waste and the extent to which they are to be removed. The degree to which treatment is required depends upon the mode of disposal of the treated waste. Different standards have been laid down for the discharge of effluents into natural water bodies, municipal sewers and onto the land.

Wastewater treatment can be classified as

i. Preliminary treatment
ii. Primary treatment
iii. Secondary treatment, and
iv. Tertiary treatment

Methods of treatment in which the application of physical forces predominate are known as *Unit Operations*. Methods of treatment in which the removal of contaminants is brought about by chemical reactions or biological agents are known as *Unit Processes*.

Preliminary treatment mainly aims at improving the flow characteristics rather than the removal of impurities.

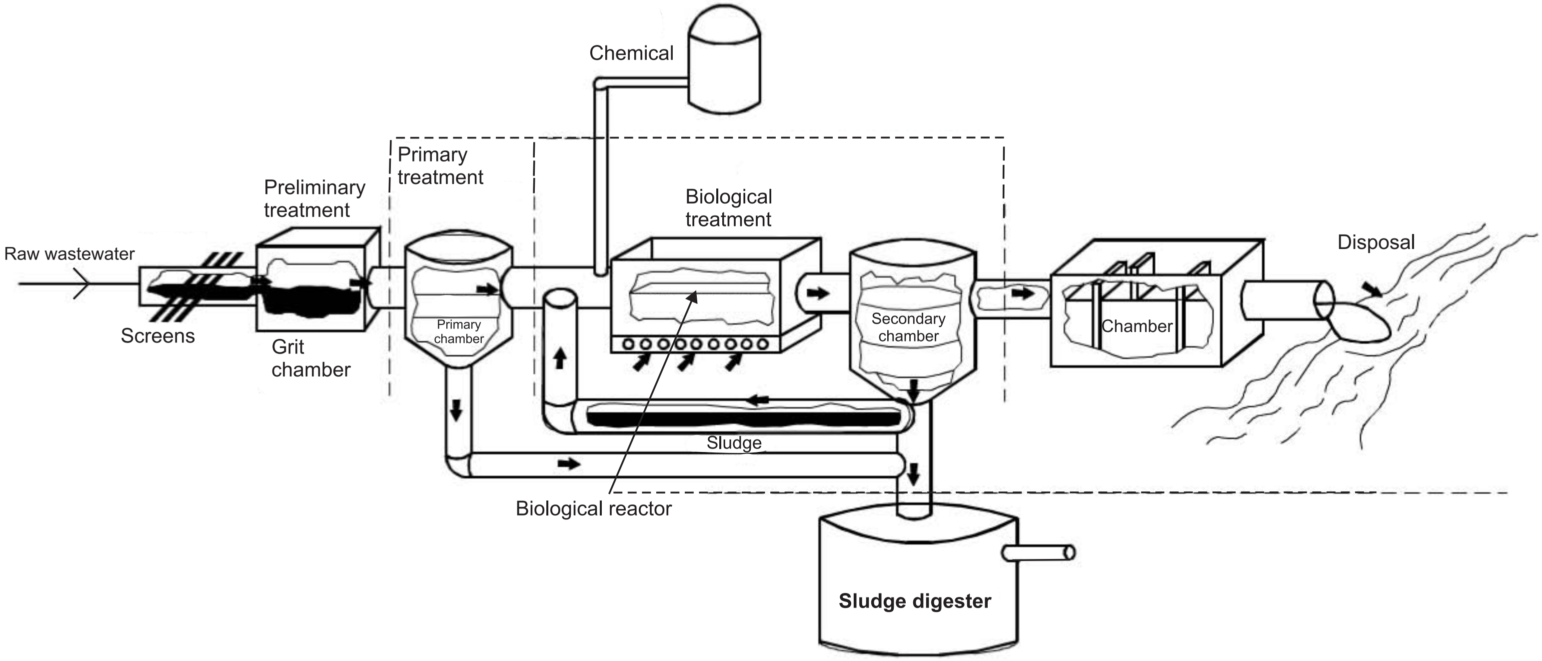


Fig. 2.1: Layout of conventional wastewater treatment plant.

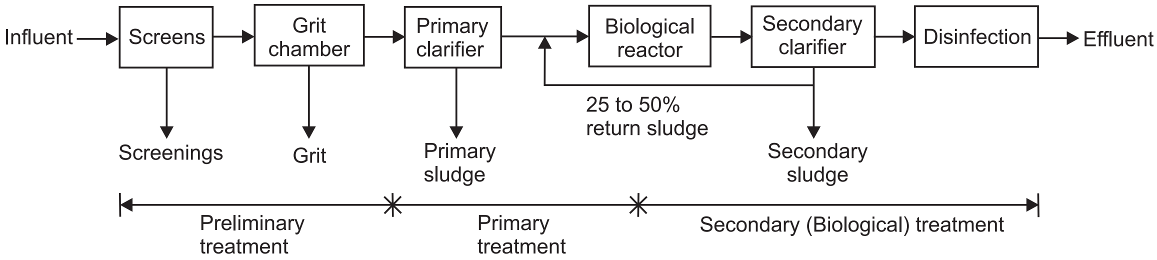


Fig. 2.1(a): Flow diagram of a conventional wastewater treatment plant.

In preliminary treatment, physical operations, such as Screening and Grit removal are used to remove the floating and heavy settleable solids found in wastewater. Screens protect sewers and pumps from clogging because of floating solids as plant leaves, rags, pieces of wood, small dead animals etc. Grit chamber removes heavy and bigger (inorganic) settleable solids which otherwise cause abrasion and mechanical wear of the mechanical equipment. Oils and greases are removed in skimming tanks to improve flow characteristics and to protect the microorganisms in the biological (secondary) treatment.

Primary treatment involves the removal of finer inorganic and coarse organic settleable solids to reduce load on the secondary treatment.

In secondary treatment, biological and chemical processes are used to remove most of the organic matter. The objectives of the biological treatment of wastewater are to coagulate and remove the nonsettleable colloidal solids and to stabilize the organic matter. For domestic wastewater (i.e. sanitary sewage) the major objective is to reduce the organic content and in many cases, is the final treatment. For industrial wastewater, the objective is to remove or reduce the concentration of organic compounds.

In tertiary treatment, additional combinations of Unit operations and Unit processes are used to remove other constituents, such as nitrogen, phosphorous and chlorides which are not removed by secondary treatment.

Table 2.1: Percentage of removal of impurities

S.No	*Unit operations/ Unit process*	*Percentage of reduction*		
		Suspended solids	*BOD*	*Total coliforms*
1.	Primary treatment	45-60	30-45	40-60
2.	Chemical treatment (*Secondary treatment*)	60-80	45-65	60-90
3.	Trickling filter	75-85	70-90	80-90
4.	Activated sludge process	85-90	90-95	90-95

Design Considerations:

1. The process loadings in the sewage treatment are based on the daily average flows. In the absence of any data, an average flow of 150 lpcd may be adopted.
2. Population equivalent is a parameter useful in the conversion of the contribution of wastes from industrial establishments for accepting into the sanitary sewer systems by the authorities concerned and serves as a basis for levying an equitable charge for the concentration and quantity of wastewater.

3. The average daily per capita contribution of suspended solids and BOD_5 are 90 g and 45 g respectively which is used for estimating population equivalent.

2.6 SCREENS

The very first unit operation in wastewater treatment is Screening. Screening is an essential step in wastewater treatment for the removal of bigger suspended and floating solids which would otherwise damage equipment, interfere with the operation of treatment units or equipments. Screens are used ahead of pumping stations, meters and as a first step in all treatment works. A screen is a device with opening generally of uniform size for removing bigger suspended or floating matter in wastewater.

The screening element consists of parallel bars, rods gratings or wiremeshes or perforated plates and the openings may be of any shape although generally they are circular or rectangular, depending on the size of the opening screens classified as coarse, medium or fine.

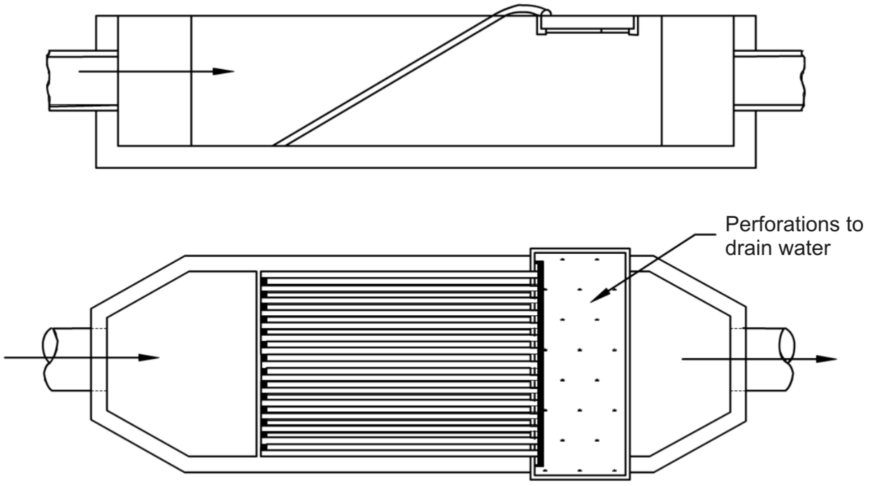


Fig.2.2: Fixed screens

Coarse screens: It is usual to provide a bar screen with relatively large openings of 75 to 150 mm and ahead of the pumps for raw wastewater while those preceding the primary sedimentation tanks have smaller openings of 50 mm.

Medium screens: Medium bar screens have clear openings of 20 to 50 mm. These screens are used before all pumps or treatment units such as the stabilization ponds.

Fine screens: Fine screens are mechanically cleaned devices using perforated plates, woven wire cloth or very closely spaced bars with clear openings of less than 20 mm. They can be fixed or of rotating type. Rotating screens with cutting blades are used to treat industrial wastes. Fine and medium screens are not normally suitable for sanitary sewage because they easily get clogged.

Quantity of screenings: The quantity of screenings varies with the size of screen used and on the nature of wastewater. Generally it has been found that the screenings from sanitary sewage vary from 0.0015 $m^3/m\ell$ with screen sizes of 100 mm to 0.015 $m^3/m\ell$ in case of 25 mm size.

Disposal of screenings: The method of disposal of screenings could be burial or composting depending on the nature or biodegradability of the wastewater.

Velocity: The velocity of flow ahead of and through a screen varies and affects its operation. The lower the velocity through the screen, the greater is the amount of screenings that would be removed from the wastewater. However, the lower the velocity, the greater would be the amount of solids deposited in the channel. Hence, the design velocity should be such as to permit 100% removal of material of certain size without undue depositions.

Velocities of 0.6 to 1.2 m/s through the screen openings for the peak flows have been used satisfactorily. When considerable amounts of storm water are to be handled, approach velocities of about 0.8 m/s are desirable, to avoid grit deposition at the bottom of the screen.

Head loss: Head loss varies with the quantity and nature of screenings allowed to accumulate between cleanings.

$$h = 0.0729\,(V^2 - v^2)$$

in which h = head loss in m

V = velocity through the screen in m/s

v = velocity before the screen in m/s

Usually accepted practice is to provide loss of head of 0.15 m but the maximum loss with clogged hand cleaned screen should not exceed 0.3 m.

Problem

Design a bar screen for a plant treating peak flow of 30 MLD of wastewater.

$$\text{Peak flow (Q)} = 30 \text{ MLD} = 30 \times 10^6 \times \frac{1}{10^3} \times \frac{1}{24 \times 60 \times 60} = 0.3472 \text{ m}^3/\text{s}$$

Assume that the velocity through the screen (at peak flow) is not allowed to exceed 0.8 m/s

$$\text{The net area of openings} = \frac{0.3472}{0.8} = 0.434 \text{ m}^2$$

Assume the depth of flow = 0.8 m

$$\text{Width of clear openings} = \frac{0.434}{0.8} = 0.5425 \text{ m} = 542.5 \text{ mm}$$

Adopting screens with bars of 10 mm × 50 mm and 20 mm clear openings

$$\text{Number of openings} = \frac{542.5}{20} \approx 28 \text{ nos}$$

Number of bars = 28 – 1 = 27

$$\text{Gross width of the screens} = \frac{28 \times 20}{1000} + \frac{27 \times 10}{1000} = 0.83 \text{ m}$$

$$\text{Velocity through screen} = \frac{0.3472}{0.83 \times 0.8} = 0.52 \text{ m/s}$$

Loss of head = $0.0729\,(V^2 - v^2)$

Loss of head = $0.0729\,(0.8^2 - 0.52^2) = 0.0269$ m (Less than 0.3 m. O.K)

Problem

Design a bar screen chamber for a flow of 10000 m^3/d.

$$\text{Rate of flow} = 10000\ \text{m}^3/\text{d} = \frac{10000}{24 \times 60 \times 60} = 0.116\ \text{m}^3/\text{s}$$

Assuming a velocity of flow of 300 mm/s

$$\text{Area of cross-section} = \frac{0.116}{0.3} = 0.387\ \text{m}^2$$

Provide 20% extra for bars

$$\text{Area} = 1.2 \times 0.387 = 0.464\ \text{m}^2$$

Assuming the screens (i.e. the bars) being inclined to the horizontal at 30°

$$\text{Vertical area of submergence} = 0.464 \times \sin 30° = 0.232\ \text{m}^2$$

$$\text{Velocity of flow} = \frac{0.116}{0.232} = 0.5\ \text{m/s}$$

Provide 6 mm × 50 mm bars 20 numbers.

$$\text{Width (B)} = 20 \times 0.006 + 21 \times 0.03 = 0.75\ \text{m}$$

$$\text{Depth (D)} = \frac{0.232}{0.75} = 0.31\ \text{m}$$

Provide 0.35 m depth.

2.7 GRIT CHAMBER

Grit chambers are designed to remove grit, consisting of sand, gravel, cinders or other heavy solid materials that have specific gravities much greater than those of the organic putrescible solids in the wastewater. Most of the substances of grit are abrasive in nature and will cause accelerated wear on pumps and sludge handling equipment with which it comes in contact. Grit deposits are not biodegradable and occupy large space in sludge digesters. It is therefore desirable to separate grit deposits from the organic suspended solids.

Grit chamber is assumed to be one in which particles settle as individual entities, and where there is no significant interaction with the neighbouring particles, which is known as free settling or discrete settling or Type I settling. Grit removal facilities basically consist of an enlarged channel area where reduced flow velocities allow grit to settle out. Mechanical scrapers remove the deposited grit.

For proper functioning of the grit chamber, the velocity through the grit chamber should not be allowed to change inspite of the change in flow. One of the most satisfactory types of automatic velocity control is achieved by providing a *Proportional Weir* at the outlet. The shape

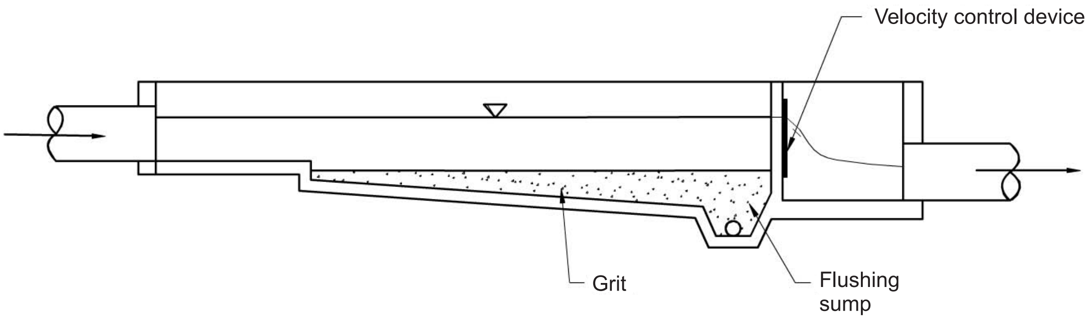


Fig. 2.3: Grit chamber

of the opening between the plates of a proportional weir is made in such a way that the chamber depth will vary directly as the discharge, as a result of which the chamber velocity will remain constant for all flow conditions.

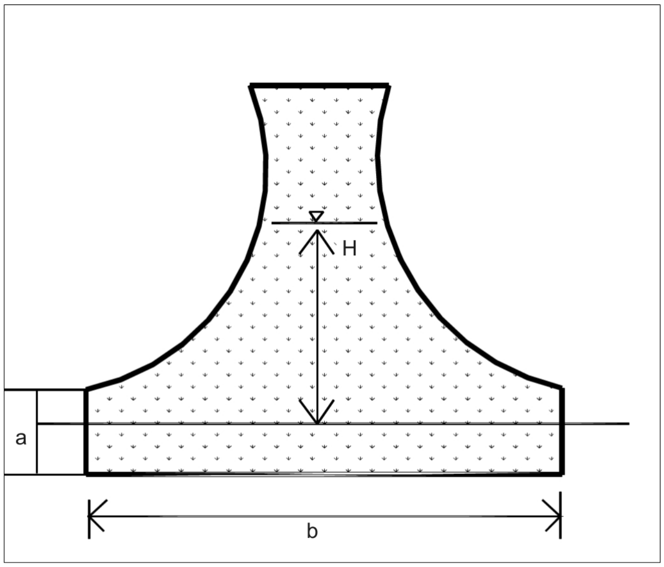


Fig. 2.4: Proportional flow weir

The flow through this weir, Q, can be given by the following formula:

$$\boxed{Q = C\, b\, \sqrt{2ag}\left(H - \frac{a}{3}\right)}$$

in which C = constant, 0.61 for symmetrical sharp edged weirs, a and b are the dimensions of the weir and H = depth of flow. The dimension of 'a' may vary from 25 mm to 50 mm.

Design Criteria

1. The design of the horizontal flow grit chambers should be such that under the most adverse conditions, all the grit particles of size 0.2 mm or more in diameter will reach the bed of the channel prior to their reaching the outlet end.

2. The length of the channel will be governed by the depth required which is again governed by the settling velocity. A minimum allowance of approximately twice the maximum depth should be given for inlet and outlet zones. An allowance of 20% to 50% of the theoretical length of the channel may be given.
3. A width in between 1m and 1.5m may be assumed. The depth of flow is normally kept shallow. A free board of about 0.3 m and a grit accumulation space of about 0.25 m should be provided above and below the effective depth.
4. A detention time of 30 to 60 seconds is recommended for the grit chambers.
5. Horizontal flow velocity V_H = 150 to 450 mm/s and a vertical settling velocity V_s = 20 mm/s are adopted.

Problem

Design a grit chamber for handling wastewater flow of 10000 m^3/d.

$$\text{Discharge} = 10000\ \text{m}^3/\text{d} = \frac{10000}{24 \times 60 \times 60} = 0.116\ \text{m}^3/\text{s}$$

Assuming a horizontal flow velocity of 0.3 m/s

$$\text{Area} = \frac{0.116}{0.3} \approx 0.39\ \text{m}^2$$

Depth (D) = 1.5 × Width (B)

B = 0.51 m and D = 0.76 m

Assume V_s (settling velocity) = 20 mm/s

$$\text{Detention time } (t_d) = \frac{d}{V_s} = \frac{0.76}{0.02} = 38\ s$$

$$\text{Length (L)} = t_d \times V_H = 38 \times 0.3 = 11.4\ \text{m}$$

Provide 20% more to overcome the outlet turbulence,

Length (L) = 13.7 m

2.8 PRIMARY SEDIMENTATION

Sedimentation is the process of separation of suspended solids from water by the force of gravity. Primary sedimentation is a unit operation designed to remove inorganic and bigger organic suspended solids from the wastewater. The purpose of sedimentation of wastewater is to separate the settleable solids so that the settled wastewater if discharged into water courses, do not form sludge deposits. Sedimentation of wastewater also reduces the organic load on secondary treatment methods. Sedimentation is the process of separation of the suspended impurities from wastewater by reducing the velocity of current of flow. Clarifier is a sedimentation tank delivering clear effluents free from suspended solids.

Secondary sedimentation or secondary settling tanks find use in settling of the effluents from secondary treatment operations like trickling filters or activated sludge process, where the flocculated organic solids produced by biological treatment are removed.

Factors Effecting Sedimentation:

1. Horizontal velocity of flow: Greater is the velocity, less is the rate of settling and longer need be the length of the tank.
2. Shape and size of the particle: Bigger particles settle quickly. Also equidimensioned particles settle quickly than flaky particles.
3. Difference of specific gravity of the particle and water: Greater the difference quicker is the rate of sedimentation.
4. Temperature of water: Greater the temperature lesser is the viscosity and rapid is the rate of settling.
5. Mass action: When neighbouring particles are settling they influence adjacent particles to settle along with them.

Stoke's Equation

$$\boxed{V_s = \frac{1}{18}\,\frac{g}{\mu}(\rho_s - \rho)d^2}$$

where V_s = settling velocity

μ = absolute viscosity of water

d = diameter of the settling particle

ρ_s = specific gravity of the settling particle

and ρ = specific of the water.

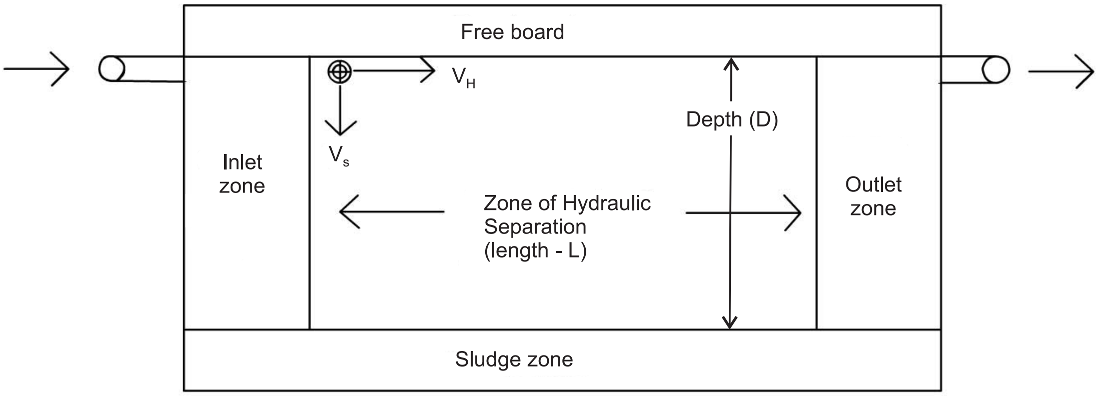


Fig. 2.5: Sedimentation tank

Detention Time:

It is the theoretical time for which a bulk amount of water is retained in the sedimentation tank. A detention period of 1½ to 2 hours is quite common for wastewater treatment.

$$\text{Detention time in days } (t) = \frac{V}{Q} = \frac{\text{Volume } \left(m^3\right)}{\text{Discharge } \left(m^3/d\right)}$$

where $V = \mathrm{L\,B\,D}$

$Q = B\,D\,V_H \;\; = L\,B\,V_s$

$$\boxed{\text{Detention time } (t) = \frac{LBD}{BDV_H} = \frac{L}{V_H}}$$

$$t = \frac{LBD}{LBV_S} = \frac{D}{V_S}$$

$$\boxed{\frac{L}{D} = \frac{V_H}{V_s}}$$

$$\frac{D}{V_s} = \frac{LBD}{Q}$$

$$\boxed{V_s = \frac{Q}{LB} = \frac{\text{Rate of flow } (Q)}{\text{Surface (plan) area}}}$$

$$\boxed{\text{Surface loading or Overflow rate or Rate of loading } (S_O) = \frac{Q}{A}}$$

$$\text{Weir loading} = \frac{\text{Rate of flow } (Q)}{\text{Length of weir}} \cdot \left(\frac{m^3/\text{day}}{m}\right)$$

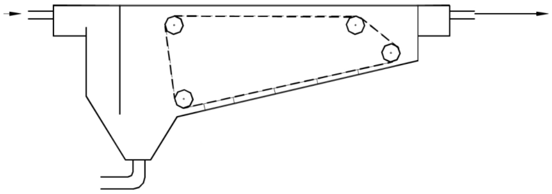


Fig. 2.6: Rectangular sedimentation tank

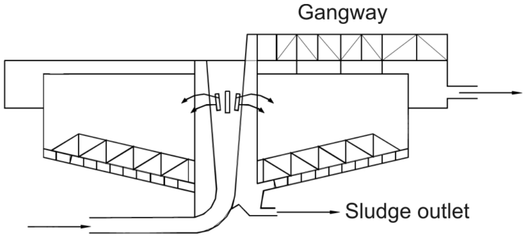


Fig. 2.7: Circular clarifier

Design Considerations:

1. Overflow rate or surface loading rate is 15 to 35 m^3/m^2/d for average flow and 40 to 50 m^3/m^2/d for peak flow. Overflow rate must be checked both at average flows and peak flows.
2. Detention time: The rate of removal of BOD and SS is maximum during the first 2 to2½ hours of settling and thereafter decreases appreciably. Longer detention time beyond 4 hours may affect the tank performance adversely due to setting in of septic conditions, particularly in tropical climates. Experience has shown that a detention period of 2 to 2½ hours for primary settling tanks and 1½ to 2 hours for secondary settling tanks will produce the optimum results.
3. Weir loading: Weir loading influences the removal of solids in sedimentation tank, particularly in secondary settling tanks where flocculated solids are settled. For all primary and secondary settling tanks, in all cases except in the case of secondary tanks for activated sludge process, weir loading not greater than 100 m^3/d/m for average flow is recommended. For secondary

settling tank in activated sludge or its modifications, the weir loading shall not exceed 150 m^3/d/m.

4. Performance: Primary sedimentation of domestic sewage may be expected to accomplish 30 to 45% removal of BOD and 45 to 60% removal of SS.

Problem

Design a secondary settling tank of an ASP for 50 MLD (peak flow) operating with an MLSS of 3000 mg/ℓ. Assume peak factor as 2.25.

Peak flow = 50 MLD

Peak factor = 2.25

$$\text{Average flow} = \frac{50}{2.25} = 23 \text{ MLD}$$

Adopting surface loading rate of 20 m^3/m^2/d at average flow (General range is 15 to 35 m^3/m^2/d)

$$\text{Surface area required} = \frac{23 \times 10^6}{10^3 \times 20} = 1150 \text{ m}^2$$

$$\text{Check surface loading for peak flow} = \frac{50 \times 10^6}{10^3 \times 1150} = 43.48 \text{ m}^3/\text{m}^2/\text{d}$$

(General range is 40 to 50 m^3/m^2/d, hence O.K.)

For a solids loading of 125 kg/d/m^2 at the average flow area required

$$= \frac{23 \times 10^6}{10^3} \times \frac{3000}{125 \times 1000} = 552 \text{ m}^2$$

$$\text{Area required for peak flow a solids loading 250 kg/d/m}^2 = \frac{50 \times 10^6}{10^3} \times \frac{3000}{250 \times 1000} = 600 \text{ m}^2$$

The higher surface area of 1150 m^2 is to be adopted.

$$\text{Adopting a circular tank diameter} = \frac{\pi d^2}{4} = 1150$$

$$\text{diameter} = \sqrt{\frac{1150 \times 4}{\pi}} = 38.26 \text{ m} \approx 40 \text{ m}$$

Problem

Design a suitable rectangular sedimentation tank (fitted with mechanical cleaning equipment) for treating sewage from a city provided with an assured public water supply system with a maximum daily demand of 12 million litres/day. Assume suitable values of detention period and velocity of flow in the tank. Make any other assumption wherever required. Assume 80% of the water be rendered sewage.

$$\text{Discharge of sewage } (Q) = \frac{80}{100} \times \frac{12 \times 10^6}{10^3} = 9600 \text{ m}^3/\text{d}$$

Assuming a surface loading rate of 40 $m^3/m^2/d$

$$\text{Plan area of the tank} = A = \frac{Q}{S_o} = \frac{9600}{40} = 240 \text{ m}^2$$

Assuming $L = 4\,B$

$L \times B = 4\,B^2 = 240$

$B = 7.75$ m

But $B \not> 6$ m, (scrapping becomes difficult otherwise) provide 2 units.

For each tank $4\,B^2 = 120$

$B = 5.5$ m and $L = 22$ m

Assuming a depth of 3 m

$$\text{Detention period } (t) = \frac{V}{Q} = \frac{24 \times 2 \times 5.5 \times 22 \times 3}{12 \times 80 \times 10} = 1.815\ h\ (<3\ h\ \text{O.K})$$

$$\text{Horizontal velocity of flow } (V_H) = \frac{L}{t} = \frac{22 \times 1000}{1.815 \times 60 \times 60} = 3.367 \text{ mm/}s\ (<10 \text{ mm/}s, \text{O.K})$$

So, provide 2 tanks of 22 m × 5.5 m × 3 m

Table 2.2: Unit operations/processes, their functions and devices used for domestic wastewater treatment

S. No	*Unit operations and process*	*Functions*	*Treatment devices*
1.	Screening	Removal of large floating suspended and settleable solids	Bar racks and screens of various description
2.	Grit removal	Removal of bigger and heavier inorganic suspended solids	Grit chamber
3.	Primary sedimentation	Removal of organic and inorganic settleable solids	Primary sedimentation tank
4. (a)	Aerobic biological suspended growth process	Conversion of colloidal, dissolved and residual suspended organic matter into settleable biofloc and stable inorganics	Activated sludge process units (and its modifications), waste stabilization ponds, aerated lagoons
(b)	Aerobic biological attached growth process	Conversion of colloidal, dissolved and residual suspended organic matter into settleable biofloc and stable inorganics	Trickling filter, rotating biological contactor
5.	Anaerobic biological growth processes	Conversion of organic matter into CH_4 and CO_2	Anaerobic filter, fluid-bed submerged media anaerobic reactor, upflow anaerobic sludge blanket reactor, anaerobic rotating biological contactor
6.	Anaerobic stabilisation of organic sludges	Conversion of organic matter into CH_4 and CO_2 and relatively stable organic residues.	Anaerobic digester

Discussion: Topics and Problems

1. Explain Preliminary, Primary and Secondary Treatment.
2. Differentiate between Equalization and Neutralization citing suitable examples for each.
3. Differentiate between Unit Operations and Unit Processes in wastewater treatment.
4. Discuss the following:
   (a) Why is it necessary to provide the grit chamber in sewage treatment plant ?
   (b) Give a longitudinal section and cross-section of a grit chamber.
5. What is the surface area required in a secondary settling tank of ASP for a quantity of wastewater 50MLD (Peak flow) operating with an MLSS of 3000 mg/ℓ? Surface loading rate 20 m^3/ m^2/d at average flow. Peak factor = 2.25.
6. Design a rectangular sedimentation tank for a population of 1,00,000. Assume any other data and mention the same clearly.
7. Discuss the design criteria for screens and grit chambers.
8. A grit chamber is to be designed for handling wastewater flow of 10,000 m^3/d. Assume the horizontal flow velocity as 0.3 m/s. Calculate the surface area of grit chamber.
9. Design a suitable Grit Chamber for a sewage treatment plant getting a dry whether flow from a separate sewerage system @ 400 ℓ/s. Assume flow velocity through the tank as 0.2 m/s and detention period of 2 minutes. The maximum flow may be assumed to be three times of dry weather flow.

3

Wastewater Biology

3.1 INTRODUCTION

Water is essential for the well being of all living organisms. In fact, life is believed to have originated in the primordial oceans approximately 3.5 billion years ago. Water has shaped evolution of biological molecules on the earth. All biological life would either perish or become inactive without water. As 70% of the earth is covered with water, it is hard to imagine that we would ever be short of water. However the addition of three descriptive terms –potable, palatable and polluted in front of the word water changes the entire picture. Most aquatic environments teem with life and wherever liquid water, an energy source, and basic nutrients exist, you will find living microbes. Microbes have learnt the art of adapting themselves to extreme conditions like saturated salt (sodium chloride) solutions, temperatures from below freezing to >110°C; thrive in waters full of toxic substances like copper, cyanide, lead, silver, gasoline, oil, benzene and a plethora of other noxious natural and man-made substances. We will be considering water from the microbial perspective of disease in this chapter.

The study of wastewater is very important with respect to public health due to the large microbial load they contain. Some of these microorganisms may be harmful as the pathogenic organisms causing various water borne diseases, whereas some others may be crucial as the decomposers of waste. The diversity of microbes generally present in surface waters and waste waters and their role in water management is dealt with.

A majority of organisms present in wastewaters are microorganisms. As these organisms are too small (1-10 micrometers) to be seen with the naked eye they require a microscope to be observed. Among all forms of life on earth, microorganisms predominate in numbers of species and in biomass, but their occurrence is generally unappreciated because of their small size.

3.2 PROKARYOTIC AND EUKARYOTIC CELLS

On the basis of presence or absence of a distinct membrane bound nucleus (the region of the cell that contains genetic information), biologists recognize the existence of two fundamentally different types of cells in the microbial world, called **prokaryotic** and **eukaryotic** cells. (Greek, *pro,* before + *cary,* kernel or nucleus + *eu,* true). Eucaryotic cells have a “true” nucleus because it is enclosed in a nuclear membrane; procaryotic cells are said to have a “primitive” nucleus because their DNA is not enclosed within a nuclear membrane. The nuclear region of a procaryotic cell is referred to as a **nucleoid**, rather than as a nucleus. The differences between the prokaryotic and eukaryotic cells are given in Table 3.1 and a typical bacterial cell is illustrated in Fig 3.1.

Table 3.1: Comparisons of eukaryotes and prokaryotes

Properties	*Prokaryote*	*Eukaryote*
Phylogenetic groups	Bacteria, Archaea	Algae, fungi, protozoa, plant and animal
Cell size	Generally < 2 μm in diameter	2 to < 100 μm in diameter
Nucleus	Absent	Present
Nucleolus	Absent	Present
DNA	Single covalently closed, circular molecule, without histones plasmids may be present	Several chromosomes linear histones aid in structure
Cell division	Binary fission	Mitosis or Meiosis
Internal membrane bound structures	Absent	Present (Mitochondria, Chloroplast, Golgibody, ER)
Ribosomes	70S	80S (70s in organelles)
Cell walls	PG in bacteria; Polysaccharides, Proteins or glycoproteins in Archaea	Not universal, absent in animals and most protozoa
Plasma membrane lipid bonds	Ester in eubacteria ether in Archaea	Ester
Sterol in membrane	Rare	Present

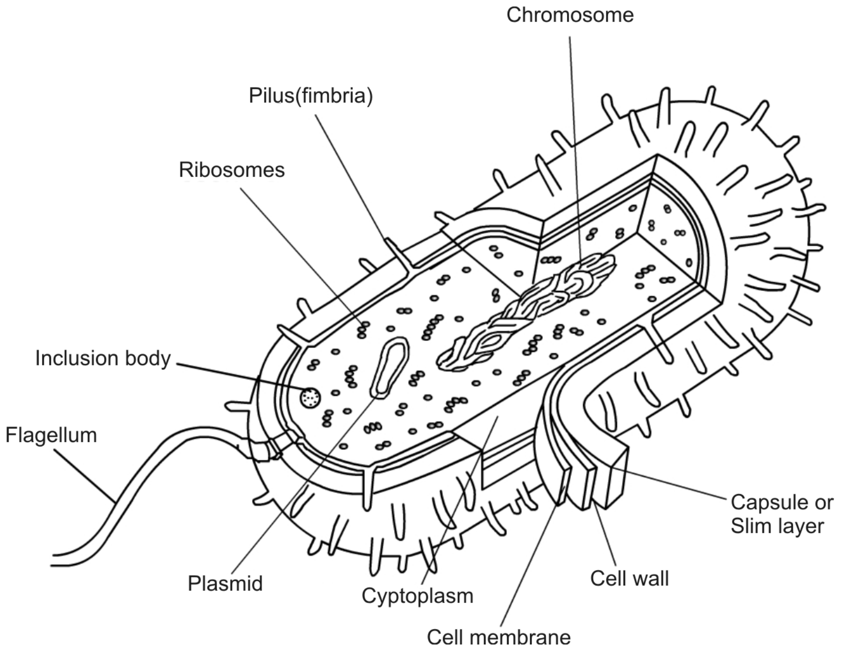


Fig. 3.1: Bacterial cell

3.3 KINDS OF MICROORGANISMS

The major groups of microorganisms are, **Archaea, Bacteria, Algae, Protozoa**, and **Fungi.** Archaea and bacteria including cyanobacteria are procaryotic cells. Eukaryotes comprise protozoa, rotifers, algae and fungi.

A brief description of these groups followed by viruses is given below:

(i) **Bacteria:** Bacteria (singular: bacterium) are unicellular organisms. Bacteria are ubiquitous in habitat and there is practically no place on the earth where no bacteria exist. There are approximately a million bacterial cells in a millilitre of fresh water; and there are approximately five nonillion (5×10^{30}) bacteria in the world.

Bacteria are typically 0.5-5 μm long and have many shapes including spheres (cocci; *sing*. coccus, Greek *kókkos*, grain, seed), rods (bacilli *sing*. bacillus, Latin *baculus*, stick), vibrio (comma shaped) and spiral shaped (spirilla). The cell wall imparts rigidity to a bacterial cell and also enables a bacterium to acquire nutrients, attach to surfaces, swim through liquids and escape predators.

The cell wall may be a homogenous thick layer made of peptidoglycan, a polymer of N-Acetylglucosamine and N-acetyl muramic acid or heterogenous. The bacterial cells are divided into G +ve and G –ve on the basis of staining property of their cells.

Bacteria being prokaryotes lack a typical nucleus and other membrane bound organelles in the cell. Both G +ve and G –ve bacteria show presence of cytoplasm, a gel like matrix in which are suspended ribosomes, chromatin material in the form of nucleoid and storage granules. Photosynthetic bacteria show presence of pigments freely in the cytoplasm. Some bacteria may show presence of mesosomes, infoldings of cytoplasmic membrane, where respiratory enzymes may be present. Prokaryotes may also contain fibrillar structures like flagella or pili for motility. Several of the G +ve bacteria are also capable of forming resistant endospores, which help them overcome stress conditions

(ii) **Archaea:** Archaea on the other hand although prokaryotic, differ from bacteria by the absence of peptidoglycan in their cell wall, the cell wall and cell membrane composition of the archaeabacteria is unique and allows them to survive in hostile conditions. Such archaeobacteria include halophiles (salt-lovers), thermoacidophiles (heat and acid lovers) and methane producing bacteria. The last of these the methanogenic bacteria have special significance in the anaerobic treatment process.

(iii) **Fungi:** One of the most important organisms bringing about recycling of minerals is fungus. All fungi are eukaryotes, they may be unicellular yeast like forms or the filamentous mycelial forms, composed of thin cottony strands called hyphae. Fungi reproduce by means of various types of uni or multicellular spores. These spores may be formed by asexual or sexual processes. All fungi are heterotrophic and require organic material as a source of energy as well as carbon.

Fungi are more important in the terrestrial habitats where they are the main organisms decomposing lignocellulosic organic debris mostly those of plants. This ability is made use of in waste water treatment where several polymers may be attacked and degraded by fungi.

(iv) **Protozoa:** Protozoa are non photosynthetic unicellular organisms exhibiting a eukaryotic cell organization. They lack cell wall, some protozoa may be covered by pellicle outside the cytoplasmic membrane. Protozoa are chemoheterotrophic and obtain their food through absorption or phagocytosis. Reproduction is by asexual or sexual process. Asexual reproduction is effected by binary or multiple fission. Protozoa are classified based on the modes of locomotion into Sarcodina, Mastigophora, Ciliophora and Sporozoa.

(v) **Rotifers:** Rotifers are multicellular animals that show an aerobic heterotrophic mode of life. These contain two sets of rotating cilia on their head used for motility and also for catching food, such as flocculated and dispensed bacterial cells, as well as smaller particles of organic matter.

(vi) **Algae:** Algae are heterogeneous organisms showing characteristic oxygen evolving type of photosynthesis. Algae are advantageous in oxidation ponds as they produce oxygen and maintain aerobic conditions. However, presence of organic nitrogen and phosphorus in water aids in uncontrolled growth of algae causing clogging of filters and pigmentation.

(vii) **Viruses:** Viruses are a unique class of obligate intracellular parasites, and are the smallest biological entities.Their size ranges from 20 nm to almost 400 nm. They require the machinery from the host cell to duplicate. Viruses show a nucleocapsid structure, with a genetic material RNA or DNA surrounded by protein capsid. Animal viruses in addition show the presence of an envelope derived from host cell membrane.

Viruses are capable of infecting all types of cells including prokaryotes (bacteria, cyanobacteria) and eukaryotes (algae, fungi, protozoa, animals and plants). Viruses can replicate only at the cost of host cell machinery. Viruses may cause a productive infection producing large number of progeny e.g. T_2, T_4 phages or show lysogeny e.g. λ phage, where the viral nucleic acid replicates only in conjunction with host chromosome. Such viruses are called temperate phages.

3.4 PATHOGENIC ORGANISMS

Contamination of food and water by microorganism is an important mode of disease transmission. These microorganisms may come from fecal contamination by either human or animal excrements. Waste water generally shows presence of pathogenic organisms belonging to bacteria, protozoa, helminthes and viruses. Common pathogenic bacteria found in waste water belong to the enteric group of bacteria. These enteric or gastrointestinal bacteria bring about large losses of money and life every year.

Bacteria: Human intestine harbours hundreds of largely harmless bacteria constituting the normal flora. These are collectively called as the enteric bacteria and show G –ve rod shaped structure. More important of these is *E. coli*, some strains of which may be pathogenic, other pathogenic organisms occupying intestines are *Salmonella*, *Shigella* etc. The enteric bacteria cause a wide spectrum of diseases, most common being the diarrheal diseases, urinary tract infections and typhoid fever caused by *Salmonella typhi*. Symptoms include continuous fever for several weeks. *S. paratyphi*, another enteric bacteria, causes paratyphoid.

Cholera: Cholera is caused by growth of enterotoxigenic *Vibrio cholerae* in the intestines. This comma shaped G –ve bacterium is transmitted by water heavily contaminated with feces or vomitus of people suffering from the disease. Cholera causes severe fluid loss from the body due to watery stools.

E.coli: Though a normal flora organism some strains causes diarrhea and dysentery like syndromes. The diarrhea occurs like a milder form of cholera. EPEC (Enteropathogenic *E. coli*) causes diarrhea in infants.

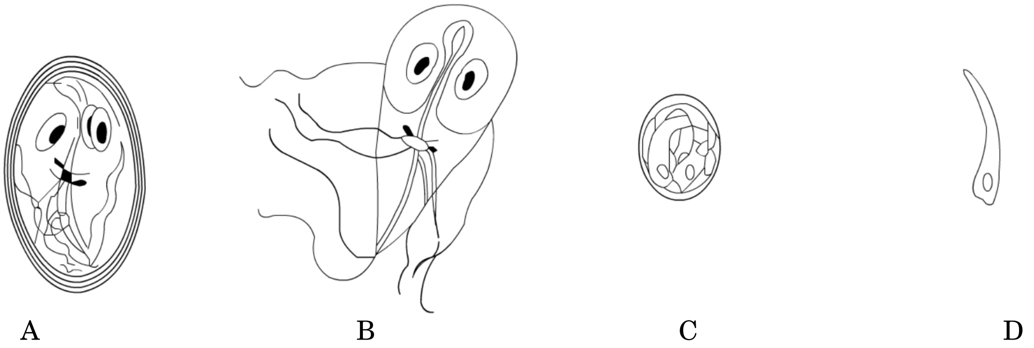
Clostridium: *Clostridium* is carried to water by contamination of feces (human or animal) or dust. It produces an enterotoxin that causes symptoms like cholera, albeit much milder.

Mycobacterium tuberculosis: Generally it spreads through sputum of infected individuals. However, it has been reported from municipal waste waters, causing infection to people coming in contact.

Pseudomonas aeruginosa: Ubiquitously found in fresh water and soil causes urinary tract infections, burn infections and pneumonias.

Protozoa: Protozoa are single celled eukaryotic microorganisms capable of causing different parasitic infections in humans and animals. A characteristic feature of some of the protozoa is the presence of a dormant phase called cyst, alternating with the vegetative phase of life cycle. The encysted cells show high resistance to chlorination and thus may cause outbreaks of infections originating from water sources. However, they can be inactivated by UV or boiling of water. Most important protozoa concerned with water contamination are *Cryptosporidium, Giardia, Entamoeba* and *Cyclospora*.

Cryptosporidium: This protozoa shows a wide spread occurrence in the intestinal tracts of animal. The small parasites are coccoid, and grow intracellularly in the epithelial cells of the stomach and intestines. The parasite causes mild diarrhea that is self- limiting in normal individuals. However, it causes severe disease, cryptosporidiasis, mostly in the immunocompromised individuals such as AIDS patients. In such individuals the infection may be life threatening.



Figs. 3.2: A, B *Giardia lamblia* C, D *Cryptosporidium cyst* and *trophozoite r*espectively

Giardia: *Giardia lamblia*, a flagellated protozoan is a frequent agent of water borne diarrhea. It is found in 97% of the surface waters of lakes and ponds. The life cycle begins when noninfected cyst is excreted out through feces of an infected individual. The cysts have a thick protective wall that resists drying and chemicals like chlorine. The cyst is characterised by 4 nuclei and a retracted cytoplasm.(Fig.3.2 A). After ingestion by a host, cysts resist stomach acid and enter the small intestines. The cyst germinates and emerges to an active state of feeding and motility (Fig. 3.2 B). It feeds on mucous inside the digestive tract and causes the host to have abdominal cramps, excessive gas, nausea, weight loss and foul smelling watery diarrhea with fat and mucous but no blood. The disease caused is called Giardiasis. As the cysts are resistant to chlorine many outbreaks of the disease are associated with water purification systems that use only chlorine (Fig. 3.3).

Entamoeba histolytica

Entamoeba histolytica causes most serious disease, amoebic dysentery, compared to other protozoa. Infection is generally due to ingestion of water or food containing *Entamoeba histolytica*

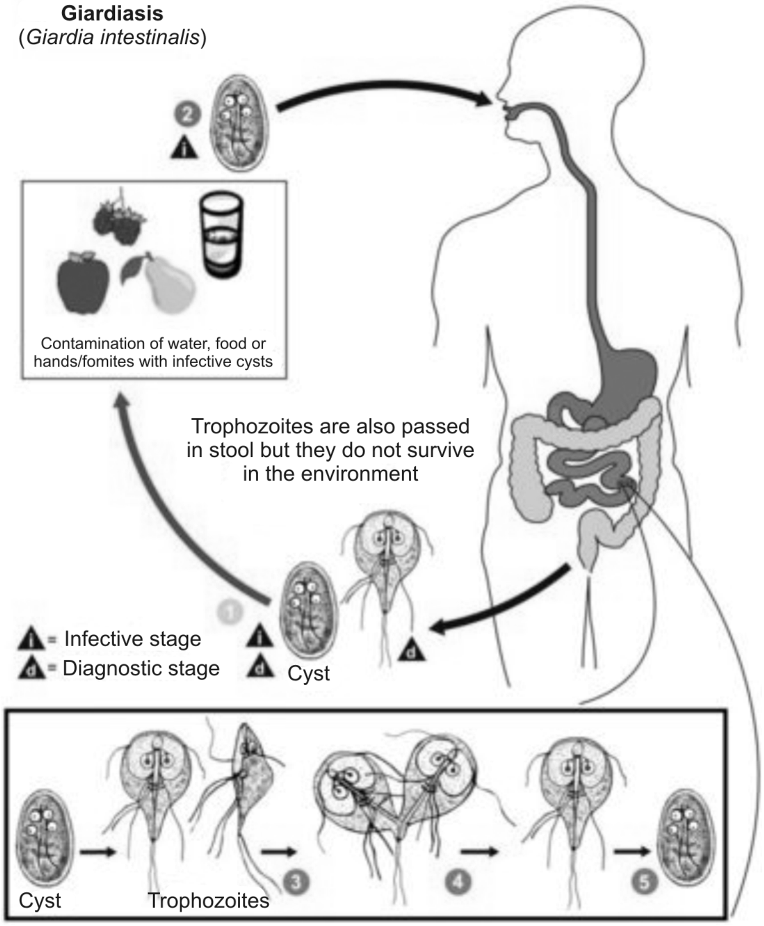


Fig. 3.3: Life cycle of *Giardia*

cysts. Cysts germinate into amebic cells in the intestines. Symptoms are mild diarrhea to severe dysentery. About 10% of world population is carrier, hence very common in water bodies if fecal pollution occurs.

Viruses

There are over 120 known enteric viruses, capable of infecting the intestinal surface of human beings. Infected people shed these viruses in their feces and contamination of water bodies may follow. Most common gastroenteritis viruses are Norwalk virus, Rota virus, Hepatitis A and Polio virus. Rota viruses are important cause of human diarrheal disease. Entero viruses cause mild gastrointestinal disease, they may infect Central Nervous System(CNS) and cause serious damage. Polio virus is an entero virus, spreads by oral fecal routé and may cause permanent paralysis if it spreads from intestines to CNS (brain or spine). Hepatitis A, another entero virus, causes infectious hepatitis, which may be mild in several cases. However, viral spread to liver increases severity of the infection.

Helminths: Helminths include worms belonging to different phyla like Nematoda (round worms), Platyhelminthes (flat worms) and Annelida (segmented worms). Round worms and flat worms are endoparasites of humans as well as several animals. *Ascaris lumbricoides* or the large round worm causes the most wide spread infections. The eggs released by the infected individual may reach water bodies and contaminate. *Taenia solium* (port tape worm) and *Taenia saginata* (beef tape worm) and *Schistosoma* (blood flukes) species are important pathogenic platyhelminthes.

Helminth eggs are the main source of infection through water. Due to their relatively large size 10 µm–100 µm helminth eggs are usually removed by processes such as sand filtration and sedimentation. However some of the helminth eggs are extremely resistant to environmental stresses and thus are not killed by chlorine disinfection. They are also capable of lying dormant and surviving.

3.5 INDICATOR ORGANISMS

One of the most important criteria to check the contamination of surface water or waste waters is the presence of pathogenic microorganisms for example *Vibrio cholerae*. However, these pathogenic microorganisms are generally present in few numbers and dispersed making it difficult to isolate and identify them from among the other non pathogenic microorganisms. Some pathogenic organisms do not have easy tests for identification. Hence, it may not be practical to examine the water specifically for the pathogenic organisms present. To overcome this problem Indicator organisms are used to test water contamination. These organisms are the more numerous (mostly non-pathogenic) species which generally occur together with the pathogenic organisms in the contaminating feces. A microorganism must show following suitable characters to be adapted as an indicator organism:

i. Must be a common inhabitant of intestine so that they are always present in feces.
ii. Indicator organisms must be present in number equal to or greater than the pathogenic organisms.
iii. It should have the same ability to survive in the environment as the corresponding pathogenic organisms.
iv. It should not replicate in the environment outside the host, to avoid problems to laboratory workers or an erroneous conclusion.
v. There should be an easier, faster and confirmatory identification method available for the indicator organism than the target pathogen.

Various indicator organisms have been proposed and used to test water contamination, the more common of which are tabulated in Table 3.2.

Table 3.2: Characteristics of indicator organisms

Indicator organism	*Characteristics*
Total coliform bacteria	Bacterial species, that are Gram –ve rods, capable of fermenting lactose with gas production, Growth at 35 ± 0.5 °C, Form a distinctive colony in 24 to 48 hours. eg. *Escherichia, citrobacter, enterobacter.*
Fecal coliform bacteria	Those bacterial species capable of producing gas or colonies at relatively higher temperatures (44.5 ± 0.2 °C)
E coli	Most common indicator organism used as a representative of coliform bacteria
Klebsiella	Capable of growing at 35 ± 0.5 °C to form gas
Clostridium perfringens	An anaerobic spore forming rod, which is used as an indicator organism to test water pollution and to check the success of disinfection
Fecal streptococci	Used to check fecal contamination of water aided by MPN method.

3.6 ENUMERATION OF BACTERIA

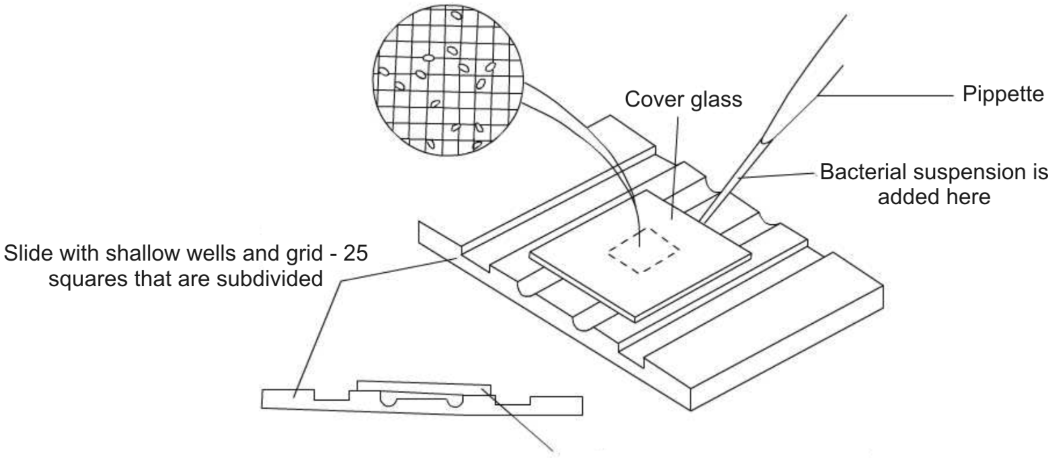
Enumeration of bacteria can be done either by directly counting the individual cells under a microscope or by indirect methods. Common methods of cell enumeration are

i. Direct cell counting
ii. Viable cell counting by plating
iii. Membrane filtration, and
iv. Multiple tube fermentation

Other methods of cell counting include fluorescent or turbidimetric measurements.

3.7 DIRECT CELL COUNTS

In this method a sample of bacterial cell suspension is observed under microscope and cells counted using special counting chambers. These chambers have a marked grid on the glass slide with smaller squares of known size such that the volume contained in this grid covered by a glass slide is precisely measured. The squares aid in counting the cells with the result being determined as number of cells/volume. However direct microscoping counting does not distinguish dead cells from living cells, unless stained with some differentiating stains like acridine orange.



Couting chamber below cover glass is filled by capillary action. The sample volume over one large square of the grid is 1/1.250,00 ml. The average number of cells counted per large square is multiplied by 1,25,000 to obtain the number per milliliter.

Fig. 3.4: Haemocytometer

3.8 VIABLE COUNTS

A viable microbial cell is that which can replicate. Viable counts are obtained by either spread or pour plate method. These methods do not take into account the dead cells present in the sample. It is assumed that each viable cell will form a distinct colony of cells on incubation. In spread plate method a very small known volume (0.1 ml) of a suitably diluted original sample is spread over an agar plate uniformly. After incubation the number of colonies are counted and the final figure is obtained after multiplying with the dilution factor. In the pour plate the diluted sample is added into a sterile plate over which molten agar medium is poured and swirled to distribute the sample throughout the agar volume. The colonies appearing after incubation are counted.

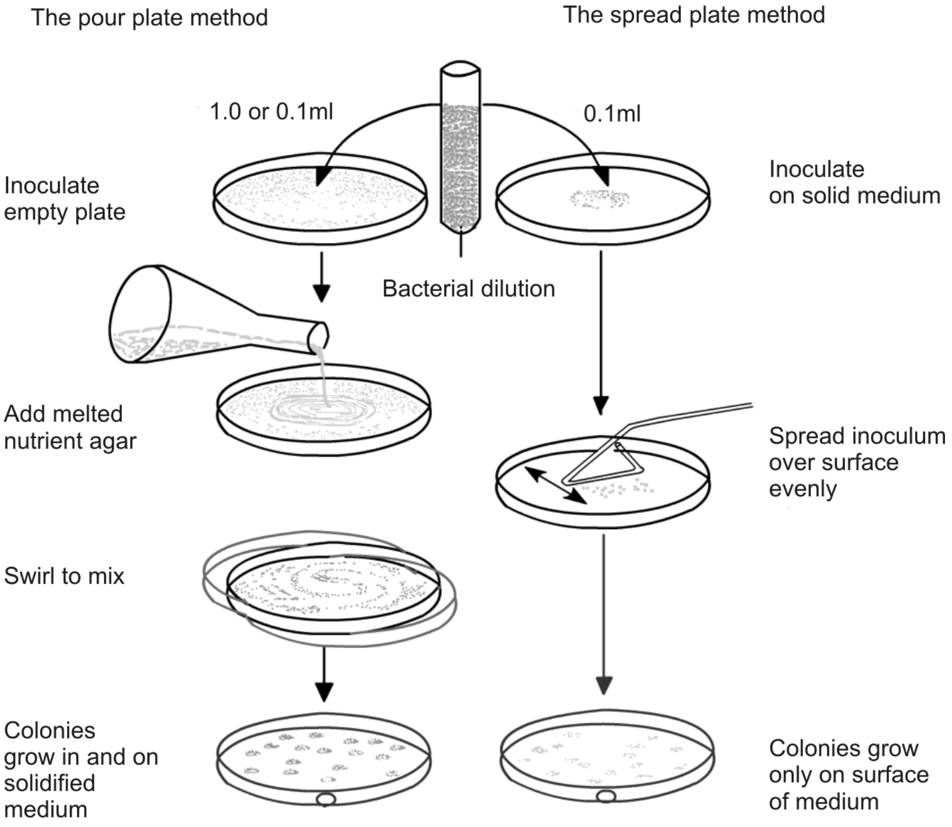


Fig. 3.5: Illustration of spread plate method and pour plate method

3.9 MEMBRANE FILTER

In the above two methods, only a small/limited volume of sample can be used for enumeration. Hence in water samples showing very low number of microbes the probability of these being observed is low. In membrane filter technique, large sample volumes can be used. The water sample is passed through a membrane filter that has pore size smaller than bacteria. The filter retains the bacteria present in the water sample. The filter is then transferred to a solid agar medium, the colonies formed can be counted. The advantage of this method is that it is faster, and allows screening of larger volumes of sample (Fig. 3.6 a).

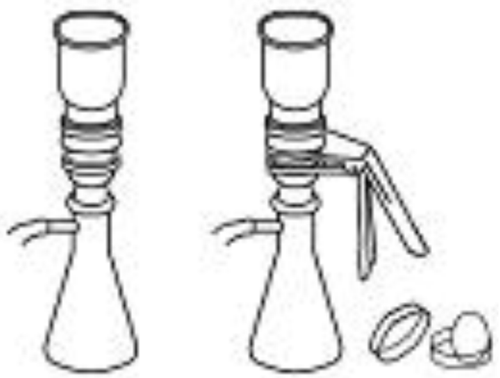


Fig. 3.6 (a): Membrane filter unit

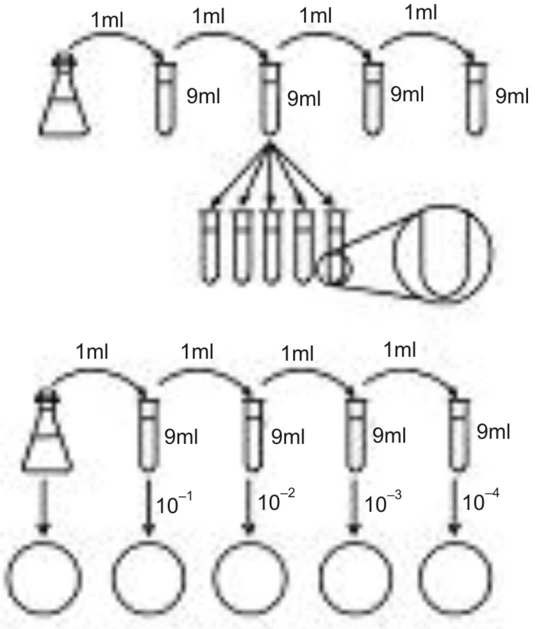


Fig. 3.6 (b): MPN method

3.10 MOST PROBABLE NUMBER (MPN) METHOD

It is an indirect method of enumerating bacteria and depends on determining the dilution of sample needed to reach the point where no growth occurs in liquid medium. It is useful when sample bacteria do not grow on solid medium. Thus MPN is a statistical method of determining the number of cells in a sample (Fig 3.6 b). Bacterial cell numbers can also be estimated by turbidity measurements using spectrophotometer or electronically, using a coulter counter.

3.11 CULTURE OF BACTERIA

The identification of pathogenic organisms particularly when there is a disease outbreak is very essential. But microorganisms do not grow singly in environment. Microbial communities exist in nature. Hence, methods and procedures for isolation of a particular microorganism from amongst the communities are very useful. An important approach to this goal is the enrichment culture technique. This technique makes use of media and a set of incubation conditions that are selective for a desired organism and counter selective for undesirable organisms. For this purpose selective and differential media are generally used.

Selective Media

Selective media comprise chemical substances that inhibit the growth of one type of bacteria while permitting the growth of another bacteria. This facilitates the isolation of bacteria of interest.

Differential Media

Differential media can distinguish morphologically and biochemically related groups of organisms. They comprise chemical compounds that produce characteristic changes in the appearance of bacterial growth and also in the medium surrounding bacterial colonies. For example Mannitol Salt Agar medium contains high concentration of salt (7.5 % NaCl) which inhibits growth of most of the bacteria other than Staphylococci.

MacConkey agar medium comprises the dye crystal violet which inhibits the growth of gram +ve organisms allowing the isolation of gram –ve bacteria. The medium contains lactose as a carbon source which permits the differentiation of enteric bacteria into two groups (a) Coliform bacilli – produce acid on fermenting lactose. The acid produced changes the colour of the medium red and the bacteria exhibit red coloration. This media is used for picking *E-coli*. (b) Bacilli causing dysentery, typhoid, paratyphoid are not lactose fermenters and do not produce acid. Hence, these bacterial colonies appear transparent and uncoloured.

3.12 IDENTIFICATION OF SPECIFIC ORGANISMS

Bacteria are identified on their morphological and biochemical characteristics based on the Bergy's manual of Bacterial identification. Of late, a variety of molecular techniques have been developed for the identification of specific bacteria. The most important of these methods include the use of fluorescent antibodies, and nuclic acid probes. These two techniques have gained importance because of their use in biological water treatment processes.

(a) Fluorescent technique: It makes use of an antibody chemically modified with fluorescent dyes like rhodamine B (fluoreses red) or fluorescene isothiocynate (fluoreses green). The fluorescentally tagged antibodies are used to detect antigens in the intact cells with the help of fluorescent microscope. Organisms to which fluorescent antibodies are attached emit red organge or yellow green colour depending on the dye used. Fluorescent antibody technique is important in the identification of many pathogenic bacteria and also *Giardia* and *Cryptosporidium*. This technique enables the identification of a pathogen directly and avoids isolation and culturing of the organism.

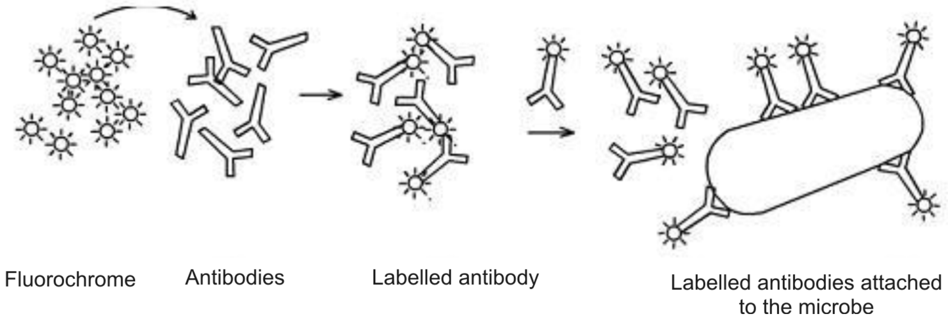


Fig. 3.7: Identification of microorganisms by fluorescence tagging

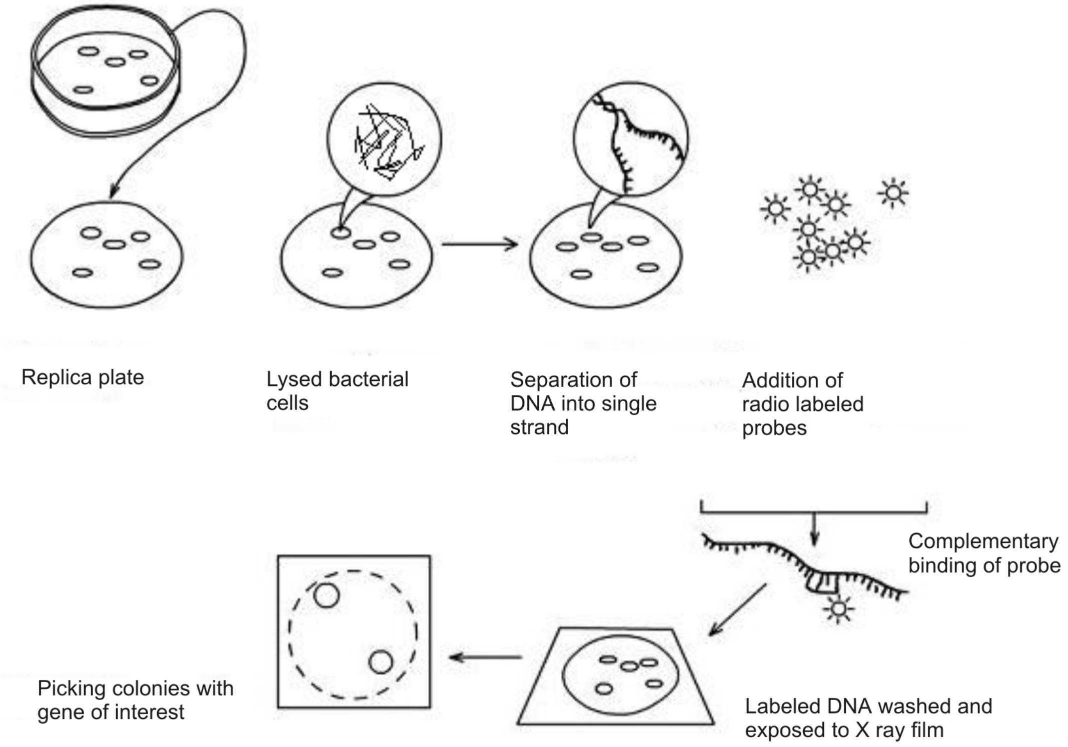


Fig. 3.8: Nucleic acid hybridization

(b) Nucleic acid hybridization: Nucleic acid hybridization is a powerful technique that does not require a whole organism but detects the presence of specific DNA sequence unique to the target organism. In order to identify a particular organism it is necessary to have a specific nucleic acid probe which is a single strand DNA containing a sequence unique to the organism of interest. When the DNA sequences of an organism are complementary to the probe, it hybridizes to form a double strand DNA molecule. As the probe is labeled with a marker like a radio isotope, enzyme or fluorescent dye, it can be measured.

Discussion:

1. Differentiate between prokaryotic and eukaryotic cells.
2. What are the major groups of microorganisms ?
3. What is the significance of indicator organisms ?
4. How can you enumerate living microbial cells ?
5. What are the molecular techniques used to identify specific microorganisms ?

4

Secondary Treatment (Biological Treatment)

4.1 AEROBIC AND ANAEROBIC TREATMENT

Primary treatment is a physico-chemical treatment that removes the pollutants which settle or float. Secondary treatment is the treatment that follows the primary treatment which delivers an effluent that got rid of most of its impurities and after which the effluent can be safely disposed of into natural courses of water.

Biological treatment is the mostly favoured secondary treatment and for that the wastewater must be predominantly *BIODEGRADABLE* i.e. $\frac{BOD}{COD} > 0.6$. Domestic sewage definitely is biodegradable. Microorganisms under favourable conditions remove dissolved organic solids and colloidal solids and get themselves removed. Large number of organisms in a small reactor decompose the organic matter in a smaller interval of time under ideal conditions operating with high efficiency.

Carbonaceous BOD removal is the biological conversion of the carbonaceous organic matter in wastewater to cell tissue and various gaseous end products. Substrate is the term used to denote the organic matter or nutrients that are converted during biological treatment. Carbonaceous organic matter in wastewater is referred to as the substrate that is converted during biological treatment.

In the removal of carbonaceous BOD, the coagulation of non settleable colloidal solids and the stabilization of organic matter are accomplished biologically using a variety of microorganisms, principally bacteria. The microorganisms are used to convert the colloidal and dissolved carbonaceous organic matter to various gases and into cell tissue. Because cell tissue has a specific gravity slightly greater than that of water, the resulting tissue can be removed from the treated liquid by gravity settling.

The major biological processes used for wastewater treatment are classified into four major groups as *aerobic* processes, *anoxic* processes, *anaerobic* processes and a combination of the *aerobic*, *anoxic* or *anaerobic* processes.

Bacteria are classified into two major groups as *heterotrophic* or *autotrophic* based on their source of nutrients. *Heterotrophs*, sometimes referred to as *saprophytes* use organic matter as both an energy and a carbon source for synthesis. These bacteria are further subdivided into three groups, *aerobic*, *anaerobic facultative aerobes* and *facultative anaerobes* based on their action toward free oxygen.

Autotrophic bacteria oxidize inorganic compounds for energy and use carbon dioxide as a carbon source.

Aerobes require free dissolved oxygen in decomposing organic matter to gain energy for growth and multiplication.

Aerobic Reactions:

$$\text{Organics} + \text{oxygen} \rightarrow CO_2 + H_2O + \text{energy}$$

Anaerobic Reactions:

Anaerobes oxidize organics in the complete absence of dissolved oxygen by using oxygen bound in other compounds, such as *nitrate* and *sulphate*

$$\text{Organics} + NO_3^- \rightarrow CO_2 + N_2 + \text{energy}$$

$$\text{Organics} + SO_4^{--} \rightarrow CO_2 + H_2S + \text{energy}$$

The individual processes are further subdivided depending on whether the treatment accomplished is *suspended-growth* systems, *attached-growth* systems or *combinations* thereof.

Suspended growth processes are the biological treatment processes in which the microorganisms responsible for the conversion of the organic matter or other constituents in the wastewater to gases and cell tissue are maintained in suspension within the liquid.

Attached-growth processes are the biological treatment in which the microorganisms responsible for the conversion of the organic matter or other constituents in the wastewater to gases and cell tissue are attached to some inert medium, such as rocks, slag or specially designed ceramic or plastic materials. Attached-growth processes are also known as *fixed-film processes.*

4.2 TRICKLING FILTERS (AEROBIC ATTACHED GROWTH PROCESS)

Trickling filters (TFs) are used to remove organic matter from wastewater. The TF is an *aerobic* treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. This type of system is common to a number of technologies such as *rotating biological contactors* and *packed bed reactors (biotowers).* These systems are known as *attached-growth* processes. In contrast, systems in which microorganisms are sustained in a liquid medium are known as *suspended-growth* processes.

Trickling filter consists of a bed of highly permeable media to which microorganisms are attached and through which wastewater is percolated or trickled.

The filter media usually consist of rocks, varying in size from 25 to 100 mm in diameter. The depth of the media varies from 0.9 to 2.5 m and 1.8 m is most common. The liquid wastewater is distributed over the top of the bed by a rotary distributor as sprays. The wastewater trickling from the top, comes in contact with the biological media and get rid of its nutrients (carbohydrates, proteins etc). Filters are constructed with an underdrain system for collecting the treated wastewater and biological solids detached from the media. The underdrain system is important both as a collection unit and as a porous structure through which air can circulate. The collected liquid is passed to a settling tank where the solids are separated from the treated wastewater.

TFs enable organic material in the wastewater to be adsorbed by a population of microorganisms (*aerobic*, *anaerobic*, and *facultative bacteria*, *fungi*, *algae*, and *protozoa*) attached to the medium as a biological film or slime layer (approximately 0.1 to 0.2 mm thick). As the wastewater comes in contact with the medium, microorganisms of the wastewater gradually attach themselves to the rock, slag, or plastic surface to form a *zoogleal* film. The organic material is then decomposed by the aerobic microorganisms in the outer part of the biological layer.

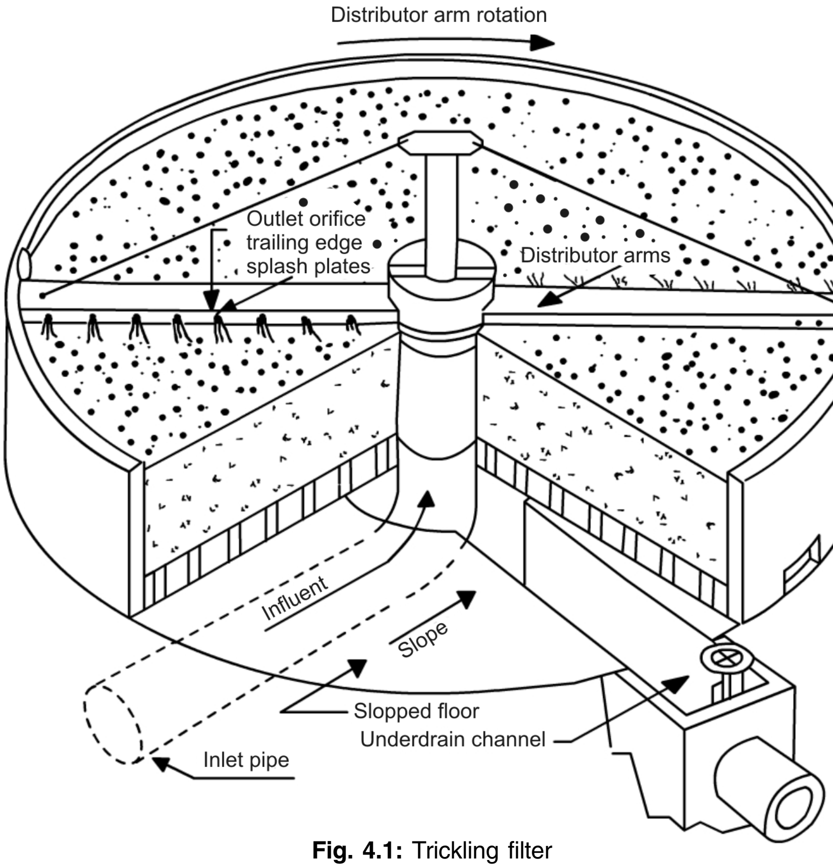


Fig. 4.1: Trickling filter

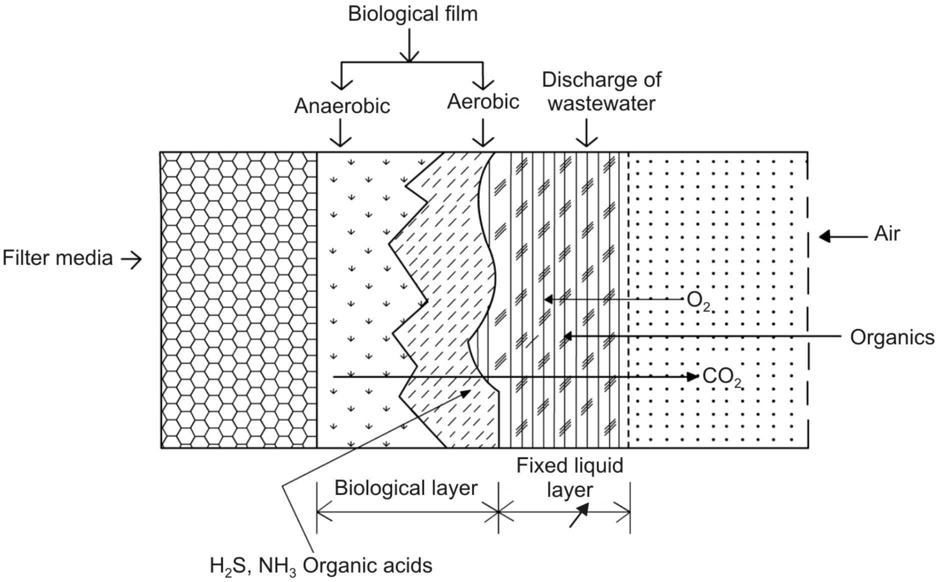


Fig. 4.2: Biological process in a filter bed (sloughing)

As the layer thickness through microbial growth, oxygen cannot penetrate through the entire thickness of the medium , and anaerobic organisms develop within. As the biological film continues to grow, the microorganisms near the free surface lose their ability to cling to the medium which is away may get detached. The detached slime layer goes down along with wastewater. This process is known as *sloughing*. Sloughing is primarily a function of organic and hydraulic loading of the filter. The sloughed solids are transported to the secondary clarifier.

4.3 ADVANTAGES AND DISADVANTAGES OF TRICKLING FILTER

Advantages

- It is a simple, reliable, biological process.
- Suitable in areas where large tracts of land are not available for intensive treatment systems.
- Effective in treating high concentrations of organics depending on the type of medium used.
- Can withstand shock loading.
- Appropriate for small-sized communities.
- Rapidly reduce soluble BOD in applied wastewater.
- Low power requirements.
- Durable process elements.
- Moderate level of skill and technical expertise needed to manage and operate the system.

Disadvantages

- Additional treatment may be needed to meet more stringent discharge standards.
- Possible accumulation of excess biomass that cannot retain anaerobic condition and can impair TF performance (maximum biomass thickness is controlled by hydraulic dosage rate, type of media, type of organic matter, temperature and nature of the biological growth).
- Incidence of clogging is relatively high.
- Requires low loadings depending on the medium.
- Vector (filter fly *Psychoda Alternata*) and odor problems exist.

On the basis of hydraulic and organic loading rates, filters are usually divided into two classes: low rate and high rate trickling filters.

4.4 STANDARD RATE TRICKLING FILTER (LOW-RATE FILTER)

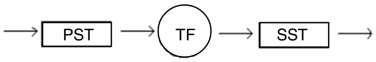
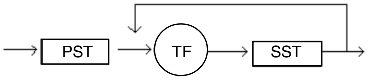
Low-rate filters are commonly used for loadings of less than 40 kilograms (five day) biochemical oxygen demand (BOD_5)/100 cubic meters per day. These systems have fewer problems than other filters with regard to filter flies, odours, and medium plugging because of the lower loading rate. Low-rate filters with a rock medium range in depth from 1.8 to 3 meters. The sloughed solids from a low-rate filter are generally well-digested and as a result these filters yield less solids than higher rate filters.

4.5 HIGH-RATE TRICKLING FILTER

It is found that as the depth of media increases aerobic conditions (sunlight and free atmospheric oxygen in particular) dwindle and hence efficiency of treatment gets reduced. This principle gave rise to the introduction of high rate trickling filter.

High rate trickling filters have less depth (not exceeding 2.5 m) and the rate of loading is almost continuous. Effluent is recycled to improve efficiency. High-rate filters are generally loaded at the maximum organic loading capabilities of the filter and receive total BOD_5 loading ranging from 0.32 to 1 kg BOD_5/m^3/day (excluding recirculation).

Table 4.1: Comparison between low rate trickling filter and high rate trickling filter

S. No.	*Item*	*Low rate trickling filter*	*High rate trickling filter*
1.	Flow diagram		
2.	Depth	1.8 to 3 m	0.9 to 2.5 m
3.	Dosing	Intermittent (5 min to 15 min)	Continuous (< 15 seconds)
4.	Recirculation ratio	0	0.5 to 3
5.	Hydraulic loading	1 to 4 $m^3/m^2.d$	10 to 40 $m^3/m^2.d$
6.	Organic loading	0.08 to 0.32 kg/m^3d	0.32 to 1 kg/m^3d
7.	Sloughing	Occasionally	Regularly
8.	BOD of the effluent	< 20 mg/l	> 30 mg/l
9.	Quality of the effluent	Highly nitrified and stable	Not fully nitrified and unstable
10.	Secondary sludge	Black, highly oxidised fine particles	Brown, not fully oxidised bigger particles
11.	Operation cost	Low	High
12.	Construction cost	High	Low

4.6 OPERATION AND MAINTENANCE

Disagreeable Odours from Filter: Excessive organic load causing anaerobic decomposition in filter and inadequate ventilation and because of it foul odours are given out occasionally.

Ponding on Filter Media: Excessive biological growth or foreign matter in or on the filter results in accumulation of wastewater without getting percolated down as the void space got reduced.

Filter Flies (Psychoda): Inadequate moisture on filter media and poor house keeping, results in proliferation of filter flies known as *Psychoda Alternata*.

Rotating Distributor Slows Down or Stops: Insufficient flow to turn distributor arm may cause its slowing down or stopping. Clogging can be prevented by screening the sewage and by efficient operation of primary sedimentation tank.

4.7 DESIGN OF TRICKLING FILTER

U.S. National Research Council (NRC)

$$\boxed{E = \frac{100}{1+0.44\sqrt{\dfrac{W}{VF}}}}$$

where W = BOD load of settled wastewater applied to filter, kg/day

V = Volume of the filter media, m^3

R = Recirculation ratio

F = Recirculation factor = $\dfrac{1+R}{(1+0.1R)^2}$

Problem

Determine the size of a high rate trickling filter for the following data:

Wastewater flow = 5 MLD = 5×10^6 ℓ/day

Recirculation ratio (R) = 1.5

BOD of raw sewage = 250 mg/ℓ

BOD removal in primary clarifier = 30%

Final effluent BOD desired = 30 mg/ℓ

$$\text{Total BOD present} = \left(5 \times 10^6\ \ell/\text{d}\right)(250\ \text{mg}/\ell)\left(10^{-6}\ \text{mg/kg}\right) = 1250\ \text{kg/d}$$

BOD left in wastewater entering the filter unit (W) = 1250 × 0.7 = 875 kg/d

$$\text{Total BOD left in effluent} = \left(5 \times 10^6\right)(30)\left(10^{-6}\right) = 150\ \text{kg/day}$$

Hence, BOD removed by filter = 875 – 150 = 725 kg/day

$$\text{Efficiency of filter} = \frac{875-150}{875} \times 100 = 82.85\%$$

$$F = \frac{1+R}{(1+0.1R)^2} = \frac{1+1.5}{(1+0.1(1.5))^2} = 1.89$$

$$\text{NRC equation} = \quad E = \frac{100}{1+0.44\sqrt{\dfrac{W}{VF}}}$$

$$82.85 = \frac{100}{1+0.44\sqrt{\dfrac{875}{V(1.89)}}}$$

$$1+0.44\sqrt{\frac{463}{V}} = \frac{100}{82.85}$$

$$1 + 0.44\sqrt{\frac{463}{V}} = 1.2070$$

$$0.44\sqrt{\frac{463}{V}} = 0.2070$$

$$\sqrt{\frac{463}{V}} = 0.4704$$

$$\frac{463}{V} = 0.2213$$

$$V = 2091.92 \text{ m}^3$$

Assume the depth of filter as 1.8 m

$$\text{Surface area of filter} = \frac{2091.92}{1.8} = 1162.18 \text{ m}^2$$

$$\text{Diameter of filter} = \sqrt{\frac{1162.18 \times 4}{\pi}} = 38.46 \text{ m say } 40 \text{ m}$$

Problem

Design a two stage trickling filter to treat a settled wastewater with a BOD_5 of 300 mg/ℓ for an average flow of 50 MLD. Assume peak factor of 2.25. The desired BOD_5 of effluent is 30 mg/ℓ. Assume organic loading rate (BOD loading) of 0.8 kg BOD_5 applied/m^3/d. Assume recirculation ratios $R_1 = 2$ and $R_2 = 1$.

Since the BOD_5 removal efficiency is high ≤ 30 mg/ℓ, a two stage filtration system has to be used.

$$\text{Total BOD load (W)} = \left(50 \times 10^6 \ \ell/\text{d}\right)\left(300 \text{ mg}/\ell\right)\left(\frac{1}{10^6} \text{ mg/kg}\right) = 15000 \text{ kg/d}$$

$$\text{Volume} = \frac{BOD_5 \text{ load kg}/d}{\text{Organic loading kg}/\text{m}^3/d} = \frac{15000}{0.8} = 18750 \text{ m}^3$$

Assume depth of filter = 2 m

$$\text{Area of filter} = 9375 \text{ m}^2$$

$$\text{Dia of filter} = 109 \text{ m}$$

$$\simeq 110 \text{ m}$$

$$R_1 = 2$$

$$F_1 = \frac{1+R}{(1+0.1R)^2} = \frac{1+2}{(1+0.1\times 2)^2} = 2.0833$$

$$E_1 = \frac{100}{1+0.44\sqrt{\frac{W}{VF}}} = \frac{100}{1+0.44\sqrt{\frac{15000}{18750\times 2.0833}}} = 78.57\ \%$$

$$\text{Total efficiency required} = \frac{300-30}{300}\times 100 = 90\%$$

Second stage (E_2) = 90% – 78.57% = 11.43%

$$R_2 = 1$$

$$F_2 = \frac{1+R}{(1+0.1R)^2} = \frac{1+1}{(1+0.1\times 1)^2} = 1.653$$

$$E_2 = \frac{100}{1+\frac{0.44}{(1-E_1)}\sqrt{\frac{W_1(1-E_1)}{V_2F_2}}}$$

$$11.43 = \frac{100}{1+\frac{0.44}{(1-0.7857)}\sqrt{\frac{15000(1-0.7857)}{V_2\times 1.653}}}$$

Volume (V_2) = 236.8 m^3.

Assume depth of filter = 2 m

Area of filter = 118.4 m

Dia of filter = 12 m

4.8 ACTIVATED SLUDGE PROCESS (AEROBIC SUSPENDED GROWTH PROCESS)

The activated sludge process is a wastewater treatment method in which the carbonaceous organic matter of wastewater provides an energy source for the production of new cells for a mixed population of microorganisms in an aquatic aerobic environment. The microbes convert carbon into cell tissue and oxidized end products that include carbon dioxide and water. In addition, a limited number of microorganisms may exist in activated sludge that obtain energy by oxidizing *ammonical nitrogen* to *nitrate nitrogen* in the process known as nitrification.

The activated sludge process is an aerobic biological treatment system. The essential units of the process are an aeration tank, a secondary settling tank, a sludge return line from the secondary settling tank to the aeration tank and an excess sludge waste line. In an Activated sludge process raw wastewater or more usually settled wastewater is aerated in an aeration tank for a period of 6 to 10 hours. During the aeration (for the upkeep of aerobic environment), the microorganisms in the wastewater multiply by assimilating part of the influent organic matter. In this process, part of the organic matter is synthesized into new cells and part is oxidized to derive energy. The synthesis reaction, followed by subsequent separation of the

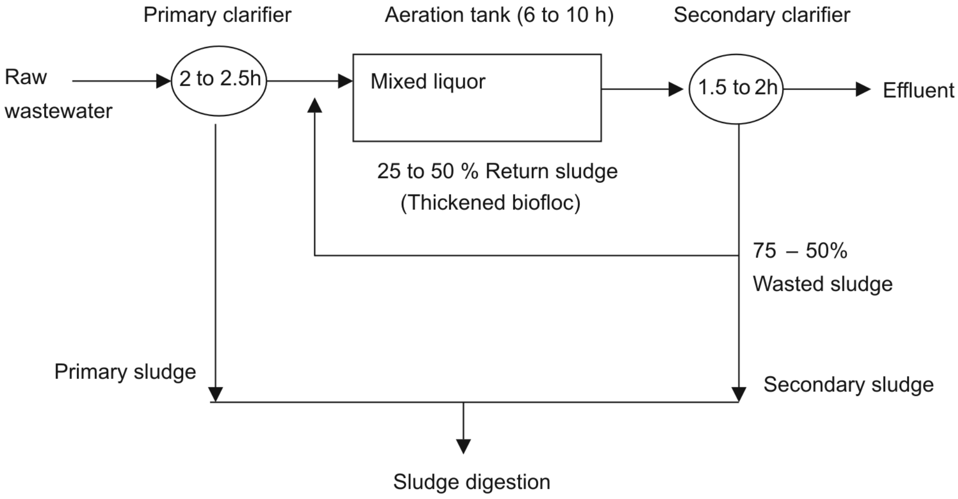


Fig. 4.3: Conventional activated sludge process

resulting biological mass and the oxidation reaction are the main mechanisms of BOD removal in the activated sludge process. The biomass is generally flocculent and quick settling. It is separated from the aerated sewage in a secondary settling tank and a part of it is recycled to the aeration tank.

Activated Sludge Process is an aerobic biological oxidation process in which wastewater is aerated in the presence of a flocculent mixed microbial culture known as *Activated Sludge*.

Wastewater rich in organics blended with return sludge rich in microorganisms is called *"Mixed Liquor"*. The microbes grow in number to remove both insoluble and soluble organics from wastewater, stabilize them and they themselves flocculate to form into clumps which settle in the secondary sedimentation tank by gravity. The process derived its name from the fact that *sludge* containing active microorganisms is returned to increase the available biomass and to speed up the reaction.

$$\underset{\text{BOD}}{\underset{\text{(org. waste)}}{\text{Food}}} + \underset{\text{MLSS}}{\underset{\text{(sludge)}}{\text{Microbes}}} + \text{Oxygen} \xrightarrow{\text{Nutrients}} \underset{\text{(surplus sludge)}}{\text{New cells}} + \text{Energy} + CO_2 + H_2O + NH_3$$

Bacteria, fungi, protozoa, and *rotifers* constitute the biological component, or *biological* mass of activated sludge. In addition, some *metazoa*, such as *nematode* worms, may be present. However, the constant agitation in the aeration tanks and sludge recirculation are deterrents to the growth of higher organisms.

The species of microorganism that dominate a system depends on environmental conditions, process design, the mode of plant operation, and the characteristics of the secondary influent wastewater.

While both *heterotrophic* and *autotrophic* bacteria reside in activated sludge, the former dominate. *Heterotrophic* bacteria obtain energy from carbonaceous organic matter in influent wastewater for the synthesis of new cells. At the same time, they release energy with the conversion of organic matter into stable compounds such as carbon dioxide and water. Important genera of heterotrophic bacteria include *Achromobacter, Alcaligenes, Arthrobacter, Citromonas, Flavobacterium, Pseudomonas,* and *Zoogloea*.

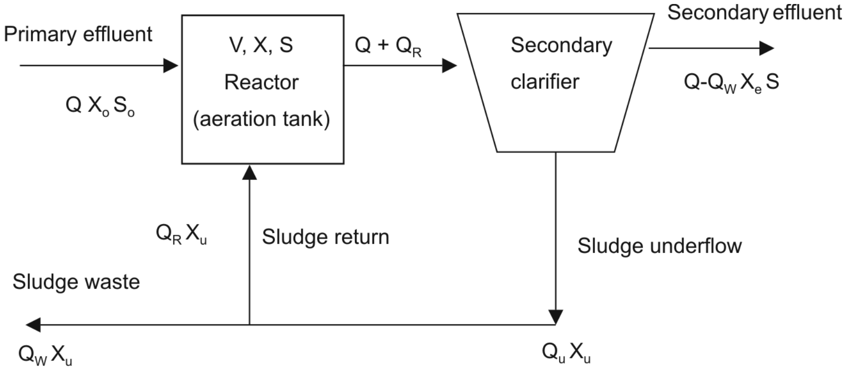


Fig. 4.4: Principle of activated sludge process

4.9 BIOLOGICAL KINETICS

Loading rate: The loading rate expresses the rate at which wastewater is applied in the aeration tank.

A loading parameter that has been developed empirically

$$\boxed{\text{Hydraulic Retention Time } (t \text{ or } \theta) = \frac{V}{Q}}$$

where V = volume of aeration tank, m^3 and Q = inflow, m^3/day X_o S_o

$$\boxed{\text{Volumetric loading rate} = \frac{QS_o}{V}}$$

where S_o = influent BOD

A rational loading parameter is the *organic loading rate* which is also referred to as *food to microorganisms ratio (F/M)*. The F/M ratio is a way of expressing BOD loading with regard to microbial mass in the system

$$\text{F/M} = \frac{Q}{V} \times \frac{BOD}{MLSS}$$

$$\text{F/M (substrate removal rate per unit solids)} = \frac{Q}{V} \times \frac{(S_o - S)}{X} = \frac{(S_o - S)}{\theta X}$$

Sludge age or mean cell residence time or

$$\text{sludge retention time } (\theta_C) = \frac{\text{mass of solids in the system}}{\text{mass of solids leaving system/day}} = \frac{X}{\Delta x / \Delta t} = \frac{X}{X_u}\left(\frac{V}{Q_W}\right)$$

The basic equation relating to solids production and substrate removal is given by

$$\frac{dX}{dt} = Y\left(\frac{dS_r}{dt}\right)$$

in which X = mass of microbial solids MLVSS
S_r = mass of soluble substrate (BOD removed)
t = time
Y = yield coefficient (0.52 kg/kg of BOD removed)

Owing to relatively long detention times in treatment processes, the cells undergo substantial decay by way of endogenous respiration

net rate production $$\left(\frac{dX}{dt}\right)_{\text{net}} = Y\left(\frac{dS_r}{dt}\right) - k_d X$$

k_d = endogenous decay rate constant/day = 0.07 to 0.1 per day.

$$\boxed{\text{net rate production } \left(\frac{\Delta X}{\Delta t}\right)_{net} = Y\left(\frac{S_o - S}{t}\right) - k_d X}$$

divide by X $$\frac{\left(\Delta X/\Delta t\right)}{X} = \frac{Y(S_o - S)}{\theta X} - k_d$$

$$\boxed{\frac{1}{\theta_c} = Y\left(F/M\right) - k_d}$$

$$\frac{1}{\theta_c} = Y(U) - k_d \quad \text{where U = substrate utilisation} = \frac{S_o - S}{\theta X}$$

$$\frac{1}{\theta_c} + k_d = \frac{Y(S_o - S)}{\theta X} = \frac{YQ(S_o - S)}{VX}$$

$$\frac{1 + k_d\theta_c}{\theta_c} = \frac{YQ(S_o - S)}{VX}$$

$$\boxed{\mathrm{V\,X} = \frac{\mathrm{Y\,Q\,(S_o - S)\,\theta_c}}{1 + \mathrm{k_d}\theta_c} \quad \text{or} \quad X = \frac{\theta_c Y(S_o - S)}{\theta(1 + k_d\theta_c)}}$$

4.10 TYPES OF PROCESSES AND MODIFICATIONS

During the year 1914 Ardern and Lockett invented the Activated Sludge Process. Modifications were proposed since then to improve efficiency, to accept shock loads, and to treat specific wastes of peculiar characteristics.

Table 4.2: Improvements to conventional activated sludge process

1. Based on physical operation	1. Plug flow (Conventional)
	2. Step aeration
	3. Contact stabilization
	4. Complete mixing
2. Based on aeration	1. Conventional aeration
	2. Tapered aeration
	3. Pure oxygen aeration
3. Based on loading and time of aeration	1. Conventional
	2. High rate
	3. Extended aeration

4.11 PLUG FLOW (CONVENTIONAL) TYPE

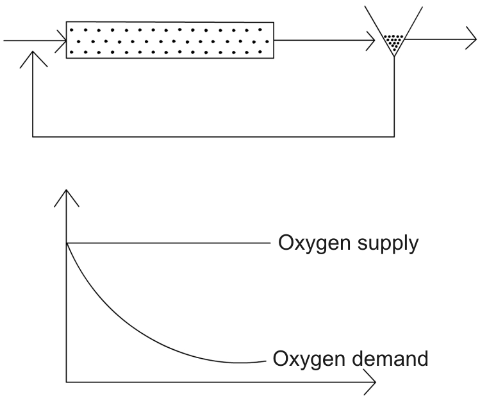


Fig. 4.5: Plug-flow (conventional) activated sludge process - oxygen supply and demand

The conventional activated sludge process consists of a long narrow aeration tank and a secondary clarifier. 25 to 50% of the secondary sludge is recycled. The recycled sludge mixed with the effluent from the primary clarifier is called *mixed liquor*. The mixed liquor is aerated for a period of about 6 hours.

Contaminant concentration (BOD i.e. the food for the microbes i.e. F) is highest at the entrance of the aeration tank and decreases rapidly with the increase in length of the aeration tank. Therefore oxygen demand is the highest at the inlet end and decreases along the length of the aeration tank. The influent wastewater and recycled sludge (which is rich in microbes i.e. M) are intimately mixed by the action of diffused or mechanical aeration. Thus at the inlet end food (F) is abundant for microbes (M) whereas their number is limited (Therefore F/M is the highest). During this period, adsorption, flocculation and oxidation of the organic matter take place and microbes multiply in number. Along the flow, the food content is decreasing (as there is no further addition of wastewater) and microbes are increasing in number (Therefore F/M decreases along the direction of flow). The solids (which mainly comprise effete microbial cells) settle in the secondary clarifier. A part of (25 to 50 %) this sludge, which is rich in microbes, is recycled to build up a high concentration of active microorganisms at the inlet end of aeration tank.

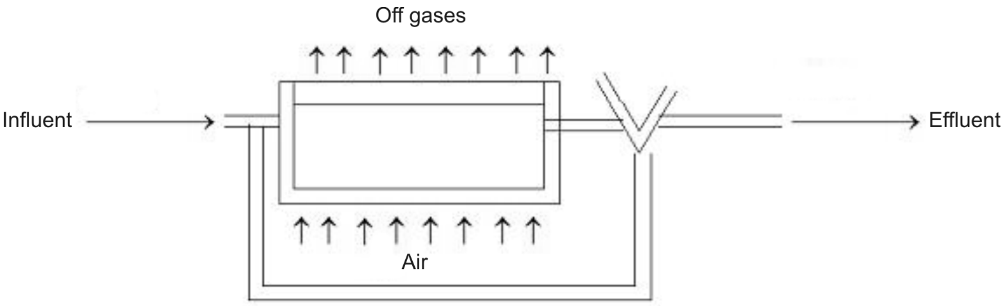


Fig. 4.6: Oxygen supply in conventional (Plug-flow) activated sludge process

Process Microbiology: Primary clarifier separates heavy inorganic and organic matter from wastewater. Thus the effluent of primary clarifier retains most of the organic solids and microbes. Return sludge (from secondary clarifier) is rich in microbes (adapted to the aeration tank environment). By mixing it with effluent from primary clarifier, optimum number of microbes are introduced into the reactor (aeration tank) to decompose wastewater. The recycling of sludge helps in the initial build up of high concentration of active microorganisms in the mixed liquor. The *mixed liquor suspended solids (MLSS)* content is generally taken as an index of the mass of active microorganisms which includes the dead cells and inert organic and inorganic matter derived from the effluent of primary clarifier. The mixed liquor volatile suspended solids (MLVSS) is preferred to MLSS as it (MLVSS) indicates the organic fraction of the sludge while MLSS includes both organic and inorganic fractions of the sludge. For sanitary sewage MLVSS/MLSS has a value of 0.8.

At the inlet end of the aeration tank wastewater rich in organic matter (carbohydrates, proteins etc.) and because of aeration aerobic environment is established conducive for the rapid multiplication of microbes. Thus along the length of flow number of microbes is increasing which in turn reduce the concentration of the wastewater (organic matter i.e. food). Thus by the time they reach the outlet end microbes are more in number (M) and wastewater almost got rid off its organic matter (F) is free from food of microorganisms. Thus they enter endogenous growth phase. The microorganisms are forced to metabolize their own protoplasm without replacement since the concentration of available food is at minimum. During this phase *lysis* occurs in which the nutrients remaining in the dead cells diffuse out to furnish food for the remaining cells. Hence effete microbes on the verge of starvation settle as sludge in secondary clarifier. When a part of the sludge is recycled these microbes are activated (by being again provided with food) and hence the sludge is called *activated sludge*.

In the above process there is a single inlet for wastewater i.e. the wastewater is more concentrated at the inlet end and the concentration depletes as it flows. But microbes are less in number at the inlet and they multiply and their number increases along the direction of flow. Thus biological activity is more and oxygen demand is more near the inlet and it ceases along the direction of flow.

4.12 STEP AERATION

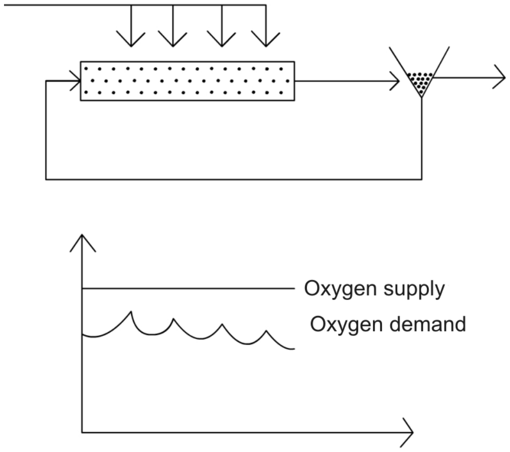


Fig. 4.7: Step-aeration activated sludge process - oxygen supply and demand

Instead of a single inlet, wastewater is introduced into the aeration tank at three or more points along the direction of flow. Thus three or more peaks exists for the bacterial activity and for oxygen demand. Food for microbes is introduced at three or more lengths keeping oxygen demand almost uniform. The aeration tank is subdivided into three or more parallel channels. Each channel acts as an aeration tank of lesser length. In this system , the oxygen demand is more uniformly spread over the length of the aeration tank, resulting in better utilization of the oxygen supplied.

The multiple point introduction of wastewater maintains an activated sludge with high absorptive properties, so that the soluble organics are removed within a relatively short contact period. Higher BOD loadings are therefore possible. The *mixed liquor suspended solids* (MLSS) is highest at the inlet end, since the full sludge recycle mixes with only part of the influent flow. This increases the SRT for the same reactor volume and sludge wasting rate. Thus volumetric loading can be increased with the same SRT, but an increased sludge wasting rate.

4.13 CONTACT STABILIZATION

Wastewater is mixed with return activated sludge in a contact reactor having a relatively short detention time of 15 to 60 minutes. During this time most readily biodegradable organic contaminants are oxidized or stored inside the cells, and the particulate matter is adsorbed to the activated sludge flocs. Then it flows into the final settling tank. The effluent of wastewater is discharged, and the settled and concentrated activated sludge is sent to a second aeration reactor called the 'stabilization tank'. Here, adsorbed organic particles, stored substrates, and biomass are oxidized. Most of the oxidation occurs in the stabilization tank. It requires skilled operation.

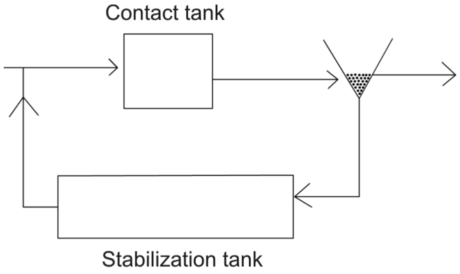


Fig. 4.8: Contact-stabilization activated sludge

4.14 CONTINUOUS FLOW STIRRED TANK

The influent settled wastewater and return sludge are introduced at several points in the aeration tank. The contents of the aeration tank are intimately mixed so that the concentration at any place i.e. inlet end to the outlet end remains almost constant i.e the F/M ratio is constant, whereas it varies from 0.7 to 0.3 for domestic sewage in Plug flow reactor. The effluent soluble contaminant concentration is uniform and low throughout the reactor. The advantage with this system is it can withstand shock loads.

4.15 TAPERED AERATION

In conventional Activated Sludge Process rate of aeration is kept uniform from the inlet to outlet whereas the demand drops drastically from inlet to outlet. As the mixed liquor traverses the aeration tank, synthesis of new cells occurs, increasing the number of microorganisms and decreasing the concentration of available food. This results in a lower food-to-microorganisms ratio and a lowering of the oxygen demand. Hence in Tapered Aeration system the supply of air is reduced along the length of flow thereby saving operational cost. Also reduction of overaeration will inhibit the growth of nitrifying bacteria which causes high oxygen demands.

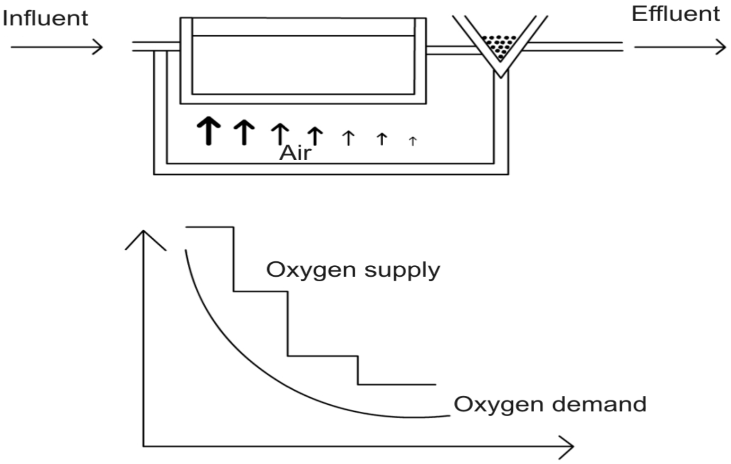


Fig. 4.9: Tapered aeration

4.16 PURE OXYGEN

Atmospheric air has only 21% of oxygen. So to meet the oxygen demand pure oxygen is supplied instead of air. Power costs for aeration and mixing can be reduced substantially. It is associated with higher MLSS concentrations, better settling of sludge, and higher volumetric loading but is expensive.

4.17 EXTENDED AERATION

The extended aeration system operates in the endogenous respiration phase of the growth curve, which necessitates a relatively low organic loading and long aeration time. The flow scheme of the extended aeration process and its mixing regime are similar to that of complete mix process. Primary settling is omitted in the extended aeration process, but screens are provided. The process employs low organic loading, long aeration time, high MLSS concentration and low F/M. The BOD removal efficiency is high. Because of long detention in the aeration tank, the mixed liquor solids undergo considerable endogenous respiration and get well stabilized. The excess sludge does not require separate digestion and can be directly dried on sand beds. The air requirements for the process are high and the running costs are also therefore quite high. However, operation is rendered simple due to the elimination of primary settling and separate sludge digestion. The method is therefore well suited for small communities having wastewater flow less than 4 MLD.

Problem

Design a Conventional Activated Sludge system that will give a final effluent that is nitrified and has a 5 day BOD not exceeding 30 mg/ℓ.

The following design data are available:

Wastewater flow rate = 10000 m^3/day BOD_5 = 400 mg/ℓ

Yield coefficient $Y = 0.6$, Decay constant $K_d = 0.07$/day

Specific substrate utilization rate $K' = 0.038$ mg/ℓ/hour

MLSS = 4000 mg/ℓ   MLVSS/MLSS = 0.8

Sludge age $\theta_c = 5$ days   Assume 30%   raw   BOD is removed in primary treatment.

30% of raw BOD is removed in primary sedimentation

BOD_5 going to aeration = 0.7(400) = 280 mg/ℓ

$$BOD_5 \text{ removal efficiency} = \frac{280-30}{280} \times 100 = 89.28\%$$

$$BOD_5 \text{ removed} = \left(10000\ \text{m}^3/\text{d}\right)(280-30)(\text{mg}/\ell)\left(\frac{10^3}{10^6}\right)\left(\ell/\text{m}^3\right) = 2500\ \text{kg/d}$$

MLVSS = 0.8 × 4000 = 3200 mg/ℓ

$$\text{V X} = \frac{Y\ Q\ (S_o - S)\ \theta_c}{1 + k_d\theta_c}$$

$$V\ (3200\ \text{mg}/\ell) = \frac{(0.6)\left(10000\ \text{m}^3/d\right)(280-30)(\text{mg}/\ell)(5\ d)}{1+(0.07)(5)}$$

$$V = 1736.11\ \text{m}^3$$

$$\text{Hydraulic Retention Time (HRT)} = \frac{V}{Q} = \frac{1736.11}{10000} \times 24 = 4.166 \text{ hours}$$

$$\text{F/M} = \frac{Q(S_o - S)}{V\ \text{X}} = \frac{(10000)(280-30)}{(1736.11)(3200)} = 0.45 \text{ kg of BOD per kg of ML VSS}$$

$$\text{Net VSS produced} = \frac{X\,V}{\theta_c} = \frac{(3200\ \text{mg}/\ell)\left(1736.11\ \text{m}^3\right)}{5\ \text{d}} \times \frac{10^3}{10^6} = 1111.11\ \text{kg/day}$$

Oxygen requirement:

= 1.47 (BOD removed) – 1.42 (net VSS produced)

= 1.47 (2500) – 1.42 (1111.11) = 87.38 kg/h

Weight of oxygen required/day:

$$= 1.47\ Q(S_o - S) - 1.42\ \text{V}\ \frac{X}{\theta_c}$$

$$= (1.47)\left(10000\ \frac{\text{m}^3}{d}\right)(280-30)\frac{10^3}{10^6} - 1.42\ \frac{(1736.11)(3200)}{5} \times \frac{10^3}{10^6}$$

= 2097.24 kg.

Problem

Design a conventional activated sludge process to treat settled wastewater with diffused air aeration system given the following data:

Settled wastewater BOD_5 = 200 mg/ℓ

Average flow = 20 MLD

Effluent BOD_5 = 25 mg/ℓ

$$\text{Efficiency required} = \frac{200-25}{200} \times 100 = 87.5\%$$

Conventional ASP select F/M = 0.2 (varies from 0.2 to 0.5)

MLSS = 3000 mg/ℓ (varies from 1500 to 3000 mg/ℓ)

$$\text{F/M} = \frac{Q(S_oS)}{V \cdot X} \cong \frac{QS_o}{V \cdot X} \quad \Rightarrow \quad 0.2 = 20 \times \frac{10^6}{10^3} \times 200(\text{mg}/\ell) \times \frac{1}{V(3000\ \text{mg}/\ell)}$$

$$V = 6666.67\ \text{m}^3$$

Check for Hydraulic Retention Time (HRT)

$$= \frac{\text{V}}{\text{Q}} = \frac{6666.67}{20 \times 1000\ \text{m}^3/d} \times 24 = 8 \text{ hours}$$ (A value between 4 and 8 hours is adopted.) Hence o.k.

Volumetric loading rate = $\frac{QS_o}{V} = 20 \times \frac{200\ \text{mg}/\ell}{6666.67\ \text{m}^3}$ = 0.6 kg BOD_5/m^3 (A value between 0.3 and 0.7 kg BOD_5/m^3 is adopted)

Return sludge (SVI = 100)

$$\frac{Q_r}{Q} = \frac{X}{\frac{10^6}{SVI} - X} = \frac{3000}{\frac{10^6}{100} - 3000} = 43\% \text{ (lies between 25 to 50\%)}$$

Tank dimensions:

Adopting a depth of 3 m and width 5 m

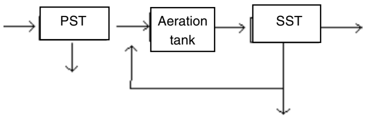
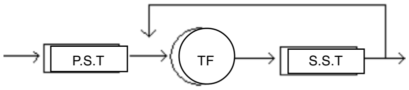
Length of aeration channel needed = (6666.67)/(3 × 5) = 444.44 m

Provide a continuous channel with ten baffles, each 45 m long to make a total length of 450 m.

Table 4.3: Characteristics and design parameters of different activated sludge systems

Process type	*MLSS mg/l*	*MLVSS / MLSS*	*F/M*	*HRT hours*	*Volumetric loading kg BOD per m^3*	*SRT days*	*Q_r / Q*	*BOD removal percentage*	*kg O_2 / kg BOD removal*	*Air requirement per kg BOD m^3*
Conventional	1500 to 3000	0.8	0.4 to 0.2	4 to 8	0.3 to 0.7	5 to 15	0.25 to 0.5	85 to 95	0.8 to 1.1	40 to 100
Step aeration	2000 to 3000	0.8	0.4 to 0.2	3 to 5	0.7 to 1.0	5 to 15	0.25 to 0.75	85 to 95	0.7 to 1.0	50 to 75
Contact stabilization	1000 to 3000	0.8	0.5 to 0.2	0.5 to 1.5	1.0 to 1.2	5 to 15	0.25 to 1.0	85 to 95	0.7 to 1.0	50 to 75
Complete mix	3000 to 6000	0.8	0.6 to 0.2	3 to 5	0.8 to 2.0	5 to 15	0.25 to 1.0	85 to 95	0.7 to 1.0	50 to 75
Tapered aeration	1500 to 3000	0.8	0.4 to 0.2	4 to 8	0.3 to 0.8	5 to 15	0.25 to 0.5	85 to 95	0.7 to 1.0	50 to 75
Extended aeration	3000 to 8000	0.5 to 0.6	0.15 to 0.05	18 to 36	0.2 to 0.4	20 to 30	0.35 to 1.5	90 to 98	1.0 to 1.2	100 to 135

Table 4.4: Comparison between activated sludge process and trickling filter

S.No	*Item*	*ASP*	*TF*
1.	Flow diagram		
2.	Nature of biological growth	Suspended growth	Attached growth
3.	Biological reaction	Fully aerobic	Anaerobes immediately in contact with media and aerobes attached to them
4.	Nature of operation	Continuous	Intermittent
5.	Microbes	Microbes needed for oxidation are supplied through the addition of 25 to 50% of return sludge	Microbes rest on the media
6.	Aeration	Wastewater is thoroughly aerated either by diffusion or by mechanical aeration	Wastewater gets aerated while getting percolated through the media
7.	Period of contact	Wastewater is subjected to aeration in the aeration tank for 6 to 10 hours	Jets of wastewater trickle down the bed when it is getting aerated. Hence the period of contact with the media is relatively less
8.	Recycling	25 to 50% of secondary sludge recycled	No recirculation in standard rate trickling filter. Effluent from SST is recycled in high rate trickling filter. Recirculation ratio 0.5 to 10.
9.	Shape of the reactor	Aeration tank is rectangular	T F can be of any shape. Circular (plan) shape is better suited when rotary arms are provided.
10.	Media	No media	Highly porous media of broken stones, coal, coke, brick bats, ceramics or synthetic as plastics
11.	Depth	3 to 4 m	Standard rate trickling filter 2.5 to 6 m High rate trickling filter 1 to 2 m
12.	Volume	<150 m^3	If circular diameter 30 to 60 m
13.	Volume of sludge delivered	Quite high	Relatively less
14.	Organic loading	500 to 650 $g/m^3.d$	100 to 400 $g/m^3.d$ for standard rate trickling filter 500 to 1500 $g/m^3.d$ for high rate trickling filter
15.	Sloughing	No	On and off in standard rate trickling filter Continuous in high rate trickling filter
16.	Fly nuisance	None	Psychoda breed on TF beds
17.	Nature of sludge delivered	Well oxidised, stable and inert	Well nitrified in standard rate trickling filter Not so well in high rate trickling filter
18.	Overall efficiency	90 to 95%	60 to 98%

4.18 ROTATING BIOLOGICAL CONTACTOR (RBC)

RBC consists of a series of closely spaced circular discs of polystyrene or polyvinyl chloride. They are so spaced that wastewater and air can enter the space between the discs. The discs are partially submerged in wastewater and rotated slowly through it. RBC has its biofilm attached to plastic media that rotate into and out of trough of wastewater. The rotation causes turbulent mixing, circulation and aeration of the liquid contents in the trough. Biological growth gets attached to the surface of the discs and forms a slime layer over the surface of the discs to a thickness of 1 to 3 mm. The rotation alternately brings the biomass in contact with the organic matter of the wastewater and free atmosphere for the adsorption of oxygen. The disk rotation affects oxygen transfer and maintains the biomass in an aerobic condition. Thus complete aerobic conditions are maintained.

Excess solids from the discs are sheared off due to rotation i.e. when the thickness of the slime layer exceeds 2 to 3 mm. RBCs are commonly used for Hydraulic loading rate of 0.04 to 0.06 m^3/m^2.d and Organic loading of 50 to 60 g/m^2.d.

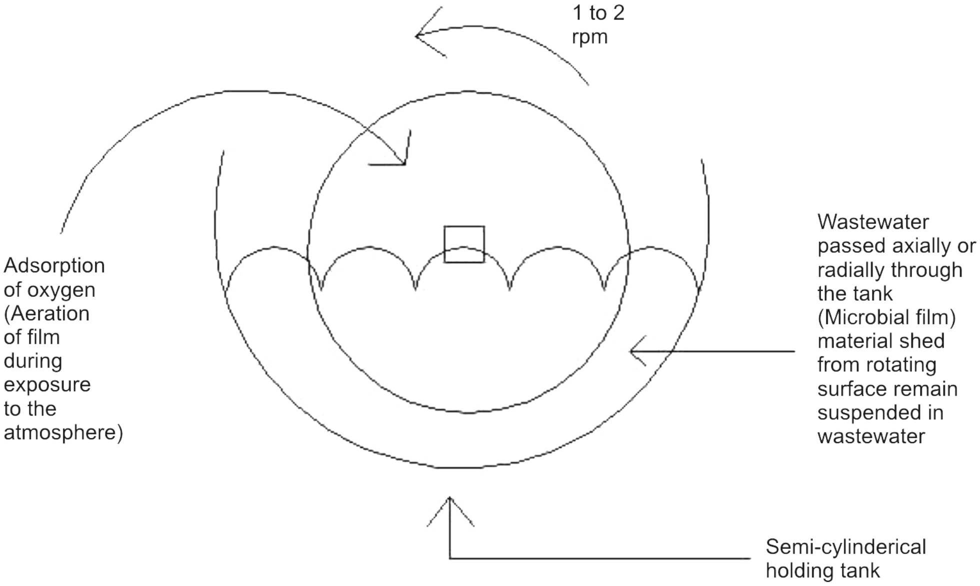


Fig. 4.10: Rotating biological contactor

4.19 STABILIZATION PONDS

Stabilization ponds are flow through earthen basins which are open to sky and specifically designed for the treatment of biodegradable industrial wastes and sewage. The putrescible organic matter of the waste is stabilized by the action of natural forces during the long detention periods. Stabilization ponds based upon the mechanism are classified as aerobic, anaerobic and facultative aerobic. In the Aerobic pond aerobic actions occur through out the depth and the oxygen required is met by algal photosynthesis. The depths are usually shallow (less than 0.5 m) and the contents are stirred occasionally so that anaerobic conditions do not develop in the settled sludge. In case of anaerobic pond the depths are comparatively larger (usually 2.5 to 4 m) and the purification is mainly from methane fermentation bacteria. The effluent here is only partially purified and the process is associated with septic odours. Anaerobic ponds are mainly used in the treatment of strong industrial wastes and have limited applications for domestic sewage treatment.

In the facultative pond the function is aerobic at surface and anaerobic at the bottom. The aerobic layer at the top prevents the evolution of odours. The treatment by facultative pond is comparable to conventional secondary treatment process. Hence it is the best suited and commonly used for sewage treatment. The mechanism of purification in a facultative pond is as follows: In the bottom layers the influent organic matter is stabilized by methane fermentation and at the top layers partly by bacterial oxidation. The algae utilize carbon dioxide in the sewage for photosynthesis during day light hours and oxygen is liberated due to which aerobic conditions are maintained in the upper layers of the pond. This oxygen is utilized by aerobic bacteria for oxidation of organic matter. Thus the principle is *algal – bacterial symbiosis*.

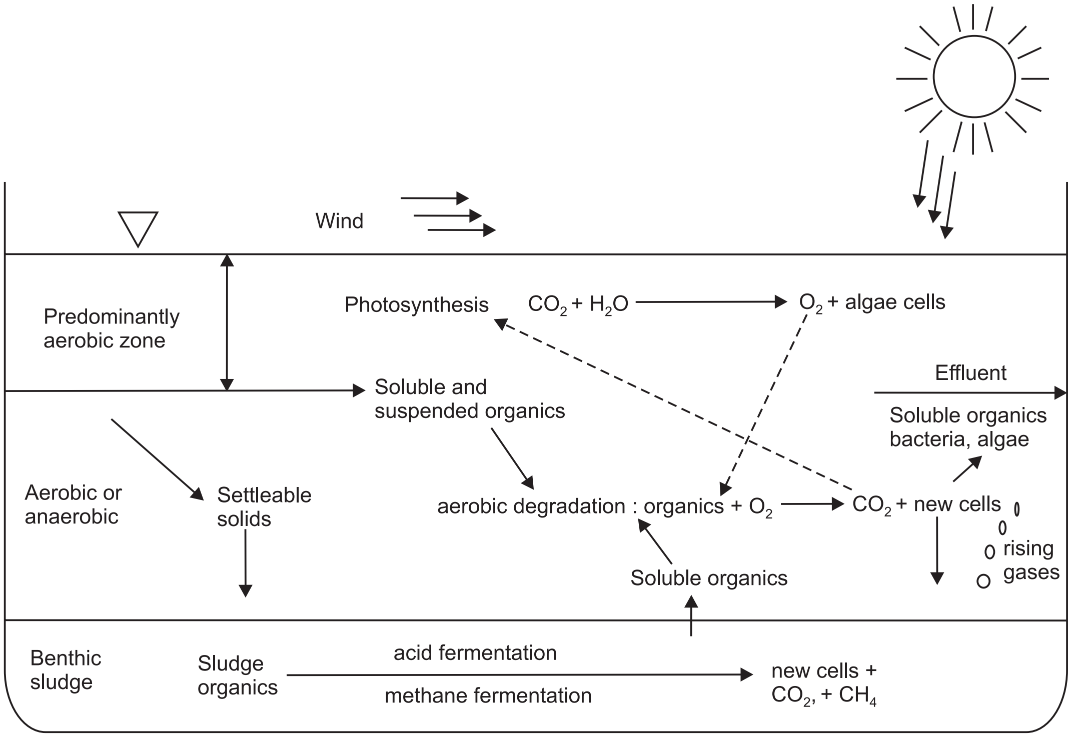


Fig. 4.11: Stabilization pond

Discussion Topics and Problems:

1. Along with neat sketches, explain the process of operation of trickling filter, design criteria and troubles associated and remedies followed in its operation.
2. What is F/M? Mention the F/M ratio to be maintained in extended type of ASP.
3. What is the purpose of recycling of effluent or secondary sludge in ASP and TF.
4. Compare and contrast ASP and TF.

5. Determine the size of a high rate trickling filter for the following data:
   Sewage flow = 5 MLD
   Recirculation ratio = 1.5
   BOD of raw sewage = 250 mg/ℓ
   BOD removal in PST = 25 %
   Final effluent BOD desired = 50 mg/ℓ
6. Design a conventional activated sludge plant to treat settled domestic sewage with diffused aeration system with following data:
   Sewage flow = 5000 m^3/d
   BOD_5 of settled sewage = 350 mg/ℓ
   BOD of treated sewage $\ngtr$ 30 mg/ℓ
   F/M = 0.6
   MLSS = 3000 mg/ℓ
   Air requirement = 100 m^3/day/Kg of BOD removed
7. Sanitary sewage from a community is to be treated in an activated sludge plant. The following data are available.
   Sewage = 240×10^6 ℓ/d
   5-day 20°C BOD = 220 mg/ℓ
   Suspended solids = 320 mg/ℓ
   MLSS = 3000 mg/ℓ
   Expected overall plant efficiency = 92%
   Determine the number and size of aeration tanks.
8. Design the required number of trickling filter units for treating domestic wastewater from a town given the following data.
   Population = 2,00,000
   Water supply = 140 lpcd
   Influent BOD onto trickling filter = 115 mg/ℓ
   Also find effluent BOD
9. What is the surface area required in a secondary settling tank of ASP to treat 50 MLD (Peak flow) operating with an MLSS of 3000 mg/ℓ. Surface loading rate 20 m^3/ m^2/d at average flow. Peak factor = 2.25.
10. In an activated sludge process the influent BOD is reduced from 250 mg/ℓ to 30 mg/ℓ. The flow Q = 4000 m^3/day, aeration tank volume 700 m^3 and MLVSS = 3000 mg/ℓ, Y = 0.5. Compute F/M ratio, and calculate the weight of net solids (sludge) produced per day.
11. Determine the efficiency of high rate trickling filter for the following data:
   Sewage flow = 5 MLD
   Recirculation ratio = 1.05
   BOD of raw sewage = 230 mg/ℓ
   BOD removal in primary clarifier = 30%
   Final effluent BOD desired = 25 m/ℓ
   Also calculate the volume of the filter.
12. For an ASP treating wastewater the following data are available
   Quantity of wastewater = 6000 m^3 /day
   Recirculation ratio = 25%
   Detention time = 6 hours
   Calculate the volume of the tank

13. A two stage trickling filter plant is to treat settled domestic sewage with a BOD_5 of 200 mg/ℓ for an average flow of 50 MLD. Assume a peak factor of 2.25. Organic loading rate (BOD Loading) 0.8 kg BOD_5 applied/m^3/d excluding recirculation. Assume recirculation ratio of 2. The desired BOD_5 of effluent is 10 mg/ℓ. Calculate the second stage efficiency required.
14. In a complete mixing activated sludge process the following design data are available:
    Total population served = 1,50,000
    Per capita sewage contribution = 150 lpcd
    BOD of settled sewage = 200 mg/ℓ
    Effluent BOD required = 10 mg/ℓ
    F/M ratio = 0.2
    MLSS = 3000 mg/ℓ

Calculate the volume of the aeration tank required.

5

Anaerobic Treatment

5.1 ANAEROBIC BASICS

Anaerobic Reactions: Aerobes need "Dissolved Oxygen" for their respiration. *Anaerobes* flourish in the complete absence of dissolved oxygen. They use oxygen in the combined state as in *nitrate* and *sulphate*

$$\text{Organics} + NO_3^- \xrightarrow{\textit{anaerobes}} CO_2 + N_2 + \text{energy}$$

$$\text{Organics} + SO_4^{--} \xrightarrow{\textit{anaerobes}} CO_2 + H_2S + \text{energy}$$

Biogas (= methane + carbon dioxide) is a product of anaerobiosis whereas aerobic processes produce no biogas.

Anaerobic treatment is relatively cheap because of its

i. Low operating costs
ii. Less sludge production
iii. Low space requirements
iv. High biogas production

5.2 PRINCIPLE OF ANAEROBIC WASTEWATER TREATMENT

Anaerobic wastewater treatment is the biological treatment without the use of air or elemental oxygen. Many groups of anaerobic bacteria "work" together in the absence of oxygen to degrade complex organic pollutants into methane and carbon dioxide (biogas). Their microbiology is more complex and delicate.

In aerobiosis aerobes work individually to decompose organic matter.

Anaerobiosis involves a number of chain reactions each being performed by a specific and specialized bacteria. *Hydrolysis* (conversion of solids into liquids), *Acidogenesis* (acid production) *Acetogenic* (acetate building) and *Methanogenic* (methane formation) phases are most common. Methane bacteria use acetic acid, hydrogen gas (H_2) and carbon dioxide (CO_2) to generate methane (CH_4).

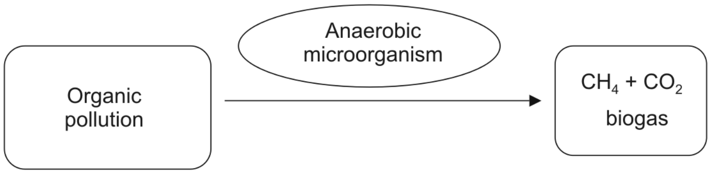


Fig. 5.1: Conversion of organic pollutants to biogas by anaerobic microorganisms

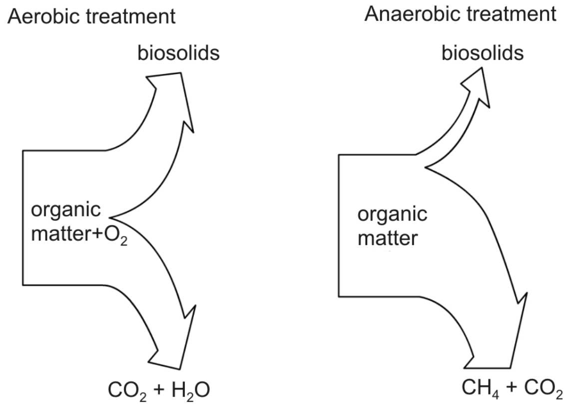


Fig. 5.2: Principles of aerobic and anaerobic treatments

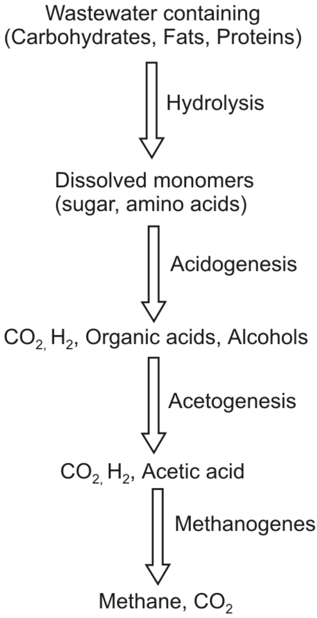


Fig. 5.3: Anaerobic microbiology

5.3 COD BALANCE

Organic pollution is measured by the weight of oxygen it consumes to oxidize pollutants chemically. This weight of oxygen is referred to as the "chemical oxygen demand" (COD). The difference between anaerobic wastewater treatment and aerobic wastewater treatment in its COD balance is shown in fig. 5.4.

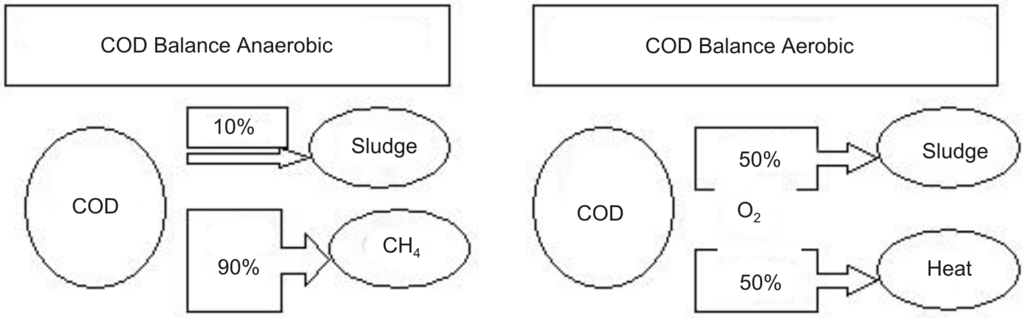


Fig. 5.4: COD balance in aerobic and anaerobic treatments

5.4 ADVANTAGES OF ANAEROBIC TREATMENT PROCESS

Less energy required: Anaerobic process requires less energy compared to aerobic process.

Less biological sludge production: As it involves less energy less biomass production occurs requiring less volume for storage.

Fewer nutrients required: Aerobic process needs more nutrients (as N, P, K) to treat industrial wastes. Their quantity is much less for anaerobic processes because less biomass is produced.

Higher volumetric loadings: Aerobic processes are designed for an organic loading of 0.5 to 3.5 kg COD/cu.m.d whereas it is 3.5 to 35 kg COD/m^3.d for anaerobic processes.

5.5 DISADVANTAGES OF ANAEROBIC TREATMENT PROCESSES

i. Anaerobiosis is relatively a slow process compared to aerobiosis.
ii. Anaerobes are more sensitive to toxic compounds than aerobes.
iii. The products of biological decomposition are more odourous, corrosive and less stable.
iv. Anaerobiosis operates in a narrow pH range and can not tolerate higher acidity (even that induced because of CO_2 production)
v. **Need for alkalinity addition:** The most significant negative factor that can affect the economics of anaerobic verses aerobic treatment is need to add alkalinity. Alkalinity of 2000 to 3000 mg/l (as $CaCO_3$) may be needed in anaerobic processes to overcome the acidity induced because of CO_2 production during the decomposition.

5.6 APPLICATIONS OF ANAEROBIC TREATMENT

Anaerobic processes are used with advantage to treat concentrated liquid organic wastewaters of distillery, brewery, pulp and paper manufacturing and petrochemical industries. At higher temperatures (as in tropics) even dilute waste (as domestic sanitary sewage) can be treated efficiently.

Anaerobic treatment processes include anaerobic suspended growth, upflow and down flow anaerobic attached growth, fluidized bed attached growth, upflow anaerobic sludge blanket reactor (UASB) etc.

5.7 ANAEROBIC SUSPENDED GROWTH PROCESS

When no media exists within the reactor for the microbes to settle but are carried along with the wastewater flow (i.e. when the microbes are in suspended state within the wastewater) it is called *Suspended Growth Processes*. Three types of anaerobic suspended growth treatment processes are:

i. The complete mix suspended growth anaerobic digester
ii. The anaerobic contact process and
iii. The anaerobic sequencing batch reactor

(i) Complete mix process: In this process the contents of the tank are intimately mixed so that fresh incoming wastewater gets intimately mixed with the old wastewater undergoing decomposition so that a homogeneous mix is obtained. For the complete mix anaerobic digester, the hydraulic(detention) retention and solids retention time (SRT) are equal. The retention time may be from 15 to 30 days depending on temperature and nature of wastewater. The complete mix digester without sludge recycle is more suitable for concentrated wastes with high concentrations of organic solids. Here no chance exists for the sludge to get separated from the wastewater as the contents are intimately mixed and no stratification can take place.

(ii) Anaerobic contact process: The anaerobic contact process overcomes the disadvantages of a complete mix process without recycle. Biomass is separated and returned to the complete mix or contact reactor so that the process SRT is longer than hydraulic retention time, therefore the anaerobic reactor volume can be reduced.

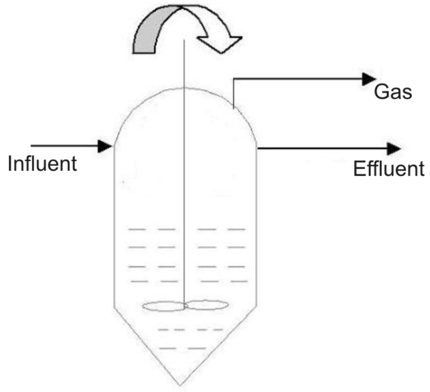


Fig. 5.5: Complete mix

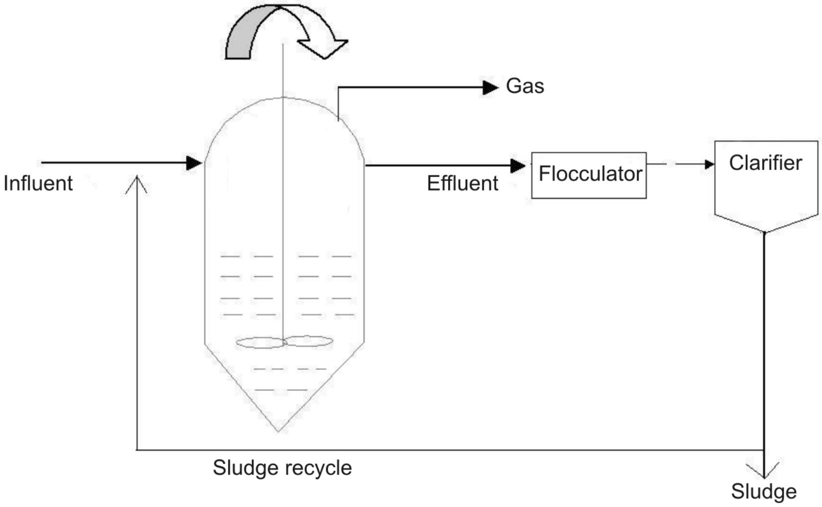


Fig. 5.6: Anaerobic contact process

(iii) Anaerobic sequencing batch reactor (ASBR): The ASBR is a suspended growth process of four stages (i) feeding (ii) reacting (mixing) (iii) settling and (iv) decanting and effluent withdrawal. A critical feature of the ASBR process is the settling velocity of the sludge during the settling period before decanting the effluent. Settling times used are about 30 min within the same reactor.

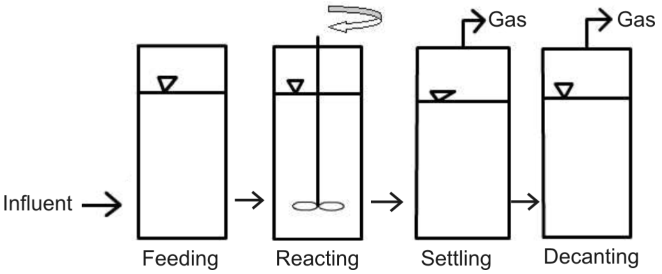


Fig. 5.7: Anaerobic Sequencing Batch Reactor (ASBR)

5.8 UPWARD FLOW ANAEROBIC SLUDGE BLANKET REACTOR

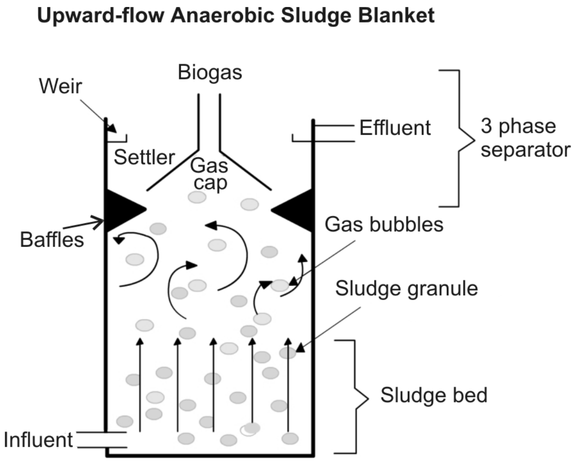


Fig. 5.8: UASB reactor

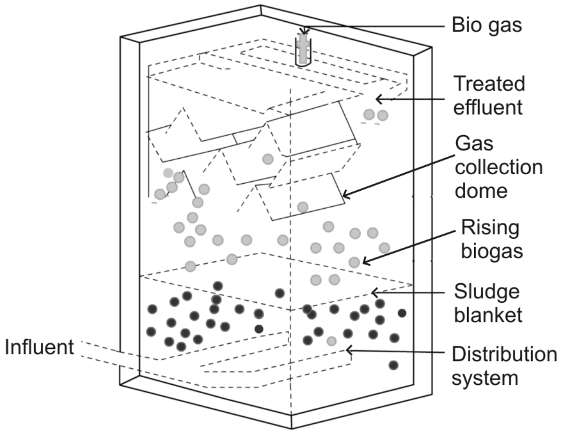


Fig. 5.9: UASB

Upward Flow Anaerobic Sludge Blanket System (UASB): It consists of a rectangular or cylindrical tank of 4 to 5 m of liquid depth. Raw wastewater subjected to screening and grit removal (but without primary sedimentation) is admitted at the bottom of this tank and made to flow upwards at a velocity of 0.15 to 0.3 mm/sec.

Its (plan) area is so designed to maintain a retention time of 8 to 10 hours. The wastewater rises up and millions of sludge particles rising up held in suspension form the base for the anaerobes to rest and degrade the organic matter.

It takes 30 to 90 days (depending on the ambient temperature) for the sludge blanket to get formed and acclimatized and the efficiency of the system increases with time. (It takes less time if the seeding is done by initially loading the reactor with sludge washout from another reactor in working condition with good efficiency). Biogas is collected at the top. Scum accumulated at the top is removed once in 2 or 3 years and this is to facilitate free flow of gas. The tank is emptied once in 5 to 7 years to improve efficiency.

For effective functioning of the system the pH is to be kept neutral and slightly on the alkaline side. The ratio of concentration of volatile fatty acids to that of alkalinity should never fall below 1:2 and if it falls below 0.5 it can be improved by the addition of bicarbonate alkalinity.

5.8.1 UASB Design Considerations

1. UASB is designed where temperature of the reactor is above 20 °C (usually between 20 °C to 25 °C)
2. Solids retention time is 30 to 50 days
3. Hydraulic retention time is 8 to 10 hours
4. Depth: 4.5 to 5 m (for domestic sewage)
5. Width or diameter: 10 to 12 m
6. Sludge blanket depth: 2 to 2.5 m (for domestic sewage)
7. Surface flow rate: 20 to 28 $m^3/m^2/d$ at peak flow
8. Upflow velocity: 0.1388 mm/sec at average flow and 0.333 mm/sec at peak flow

Reactor Volume and Dimensions

To determine the required reactor volume and dimensions, the organic loading, velocity of flow, and effective treatment volume are to be considered. *The effective treatment volume* is that occupied by the sludge blanket and active biomass. Some more volume exists between the sludge space and gas space in which zone the biomass is dilute, and sedimentation of solids is relatively less.

Organic loading rate is given by

$$L_{\text{org}} = \frac{QS_o}{V_n}$$

where V_n = effective (nominal/sludge blanket) liquid volume of reactor, m^3

Q = rate of flow, m^3/day

S_o = influent COD, kg/COD/m^3

L_{org} = organic loading rate, kg COD/ m^3.d

Total liquid volume of the reactor is given by

$$V_L = \frac{V_n}{E}$$

where V_L = total liquid volume of reactor, m^3

V_n = effective liquid volume of reactor, m^3

E = effectiveness factor (0.8 to 0.9)

If the area of cross section is 'A'

$$A = \frac{Q}{V}$$

Liquid depth of reactor $H_L = \dfrac{V_L}{A}$

An additional height of 2.5 to 3 m is to be provided extra as the gas storage space.

$$H_T = H_L + H_G.$$

Problem

For an UASB treatment process treating industrial wastewater, determine the (i) size and dimensions of the reactor and (ii) detention time given:

Flow rate (Q) = 1200 m^3/day

COD (Influent) S_o = 2200 g/m^3 = 2.2 kg COD/ m^3

Average organic loading = 10 kg COD/m^3.d

Reactor volume effectiveness factor = 90%

Wastewater upflow velocity = 1.5 m/h

$$V_n = \frac{QS_o}{L_{\text{org}}} = \frac{(1200\ \text{m}^3/d)(2.2\ \text{kg.COD/m}^3)}{(10\ \text{kg.COD/m}^3.d)} = 264\ \text{m}^3$$

Total reactor liquid volume $V_L = \dfrac{V_n}{E} = \dfrac{264}{0.9} = 294\ \text{m}^3$

$$A = \frac{Q}{V} = \frac{(1200\ \text{m}^3/\text{d})}{(1.5\ \text{m/h})(24\ \text{h/d})} = 33.33\ \text{m}^2$$

$$A = \frac{\pi d^2}{4} = 33.33$$

Diameter (d) = 6.5 m

Liquid height $H_L = \dfrac{V_L}{A} = \dfrac{294}{33.33} = 8.82$ m

Total height of the reactor $H_T = H_L + H_G = 8.82 + 2.5 = 11.32$ m

Reactor dimensions:

Diameter: 6.5 m, Height: 11.32 m

Hydraulic retention time = $\dfrac{V_L}{Q} = \dfrac{(294\ \text{m}^3)(24\ \text{h/d})}{(1200\ \text{m}^3/\text{d})} = 5.89$ hours

5.9 SEPTIC TANK

Septic tanks are used for the treatment of wastes from scattered, isolated and individual houses. It may be regarded as a downward flow sludge blanket system. The septic tank is an anaerobic treatment plant where (i) settling of solids (ii) floatation of grease (iii) anaerobic decomposition of organic matter and (iv) anaerobic digestion of sludge take place.

A septic tank is a combined sedimentation cum digestion tank. The removal of settleable solids and the anaerobic digestion of these solids are taking place simultaneously. The tank is kept completely covered at the top with a provision of a high vertical vent for the escape of the gases. Gases such as methane, carbon dioxide, and hydrogen sulphide are released during the digestion process.

The effluent contains considerable BOD and at times may be more than that of the influent. The effluent contains considerable amount of dissolved and suspended putrescible organic solids and viable pathogens. The effluent must be treated before letting off into natural open drains or natural courses of water. It is disposed of either by sub-surface irrigation or into soak pits.

Due to anaerobic digestion of sludge and consequent release of gases, appreciable reduction in the volume of sludge takes place. It is essential that adequate storage capacity be provided so that the deposited sludge remains in the tank for a sufficient length of time to undergo decomposition or digestion before being withdrawn. In general, sludge should be removed once in every 3 to 5 years.

Design Considerations:

1. **Shape:** Generally rectangular
   Minimum length = 1.5 m
   Minimum breadth = 0.75 m
   L : B = 2 : 1 or 3 : 1 or 4 : 1
   Liquid depth = 1.2 to 2.5 m
2. **Detention period:** 24 hours (most common)
   it ranges from 8 to 48 hours depending on the ambient temperature
3. **Sludge contribution:** 75 ℓ/capita/year
4. **Minimum volume:** 3 m^3
5. **Free board:** 0.5 m
6. **Bottom slope:** 5 to 10%
7. **Ventilation stack:** > 50 mm in diameter

Problem

Design a septic tank for a small colony of 40 houses and each house having on an average of 5 persons. Assume average sewage flow as 100 ℓ/capita/day.

Total population = 40 × 5 = 200

Total quantity of sewage produced per day = 200 × 100 = 20000 ℓ = 20 m^3

Assuming a detention period of 24 hours

Volume of the liquid = 20 m^3

Assuming sludge contribution = 75 ℓ/capita/year and septic tank to be desludged once in every 5 years

Maximum volume of sludge accumulated = 5 × 75 × 200 = 75000 ℓ = 75 m^3

Total volume of the liquid + sludge = 95 m^3

Assuming a liquid depth of 2 m

Area of the septic tank = 95/2 = 47.5 m^2

Let $L = 3B$

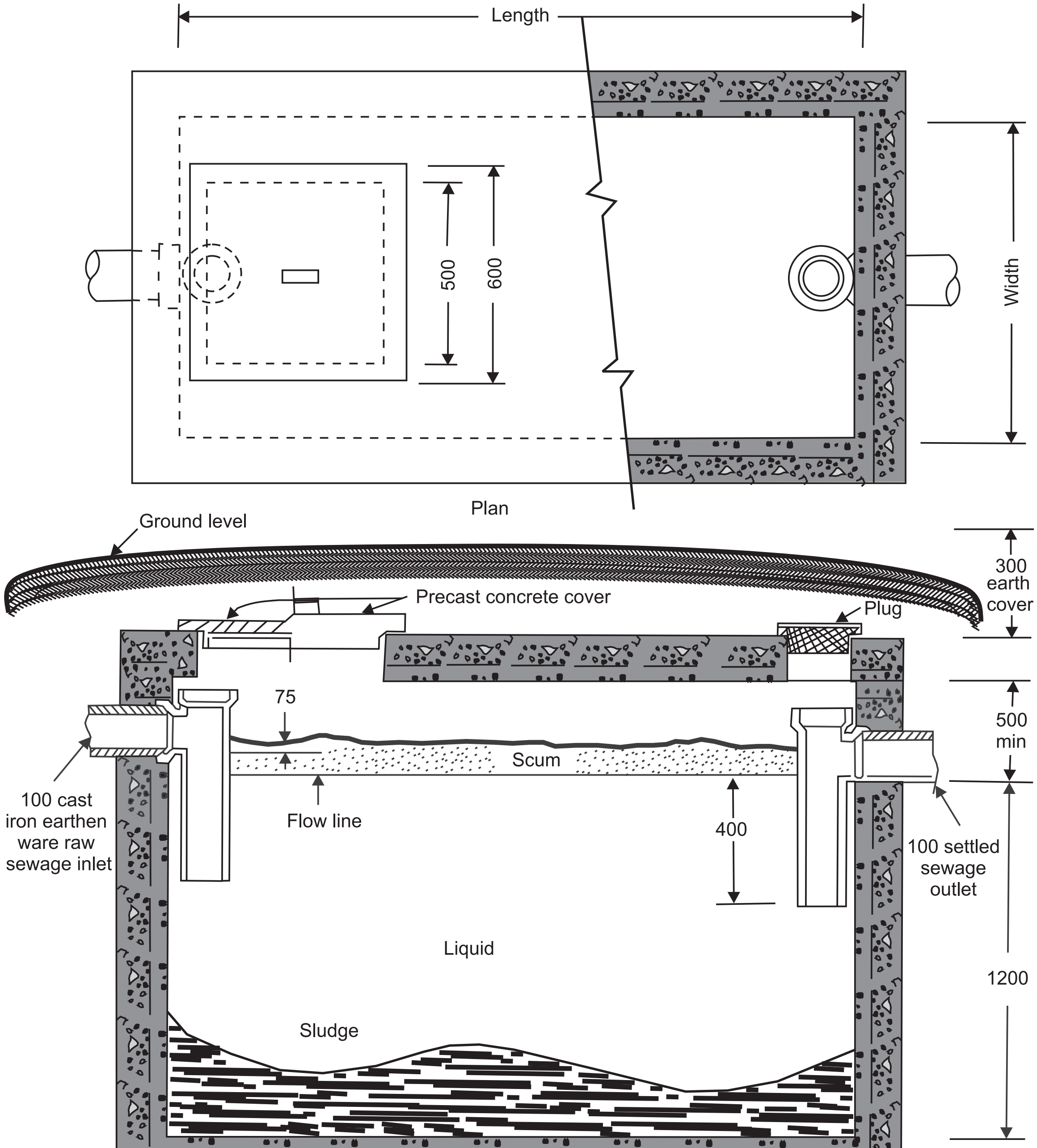
$3B^2 = 47.5$

$B^2 = 16$

$B = 4$ m

$L = 12$ m

Provide a septic tank of length 12 m, breadth 4 m and overall depth (2 m liquid depth + 0.5 m free board) 2.5 m.



All dimensions are in mm

Fig. 5.10: Details for small septic tank

5.10 ATTACHED GROWTH ANAEROBIC PROCESS

Upflow attached growth anaerobic treatment reactors can be further classified based on the type of packing used and the degree of bed expansion.

(i) **Upflow packed bed attached growth reactor:** They are similar to trickling filters as far as the media is concerned. The packing material can be broken stone or plastics. However, they are only 2 to 8 m in diameter. The media is always submerged with wastewater as the flow is upwards. While the microbes of trickling filter rest on the medium, most of the microbes of upward flow attached growth anaerobic process is loosely held in the void space of packing space.

While its depth is 3 to 13 m as in trickling filters, media packing may extend through the full depth or may just get confined to the top 50 % to 70% of the depth. The organic loading rate is relatively high i.e. 1 to 6 kg (COD)/m^3.d.

Most common operational problem is getting clogged because of voids getting filled up. Flushing is done to remedy the situation. So, this process is best suited to treat wastewaters with less suspended solids.

(ii) **Upflow attached growth anaerobic expanded bed reactor (AEBR):** In this reactor very fine media as sand (0.2 to 0.5 mm) is used instead of broken stone. Sand being finer, offers more surface area (to support microbes) for the same volume of broken stone. However, sand when soaked under water undergoes expansion. When this expansion is 20% or less sand still retains the properties of the medium and hence called Expanded bed reactor.

(iii) **Attached growth anaerobic fluidized bed reactor (FBR):** When sand undergoes 100% expansion it behaves as a fluid and hence called fluidized bed reactor. Its working principle is the same as AEBR. It is designed for an upward flow of 5.55 mm/sec. The tank may have a depth of 4 to 6 m. Activated carbon or other similar adsorbing media (0.6 to 0.8 mm in dia) may be used instead of fine sand. FBR can take an organic loading rate of 10 to 20 kg (COD)/m^3.d.

The advantages for the anaerobic FBR process include the ability to provide high biomass concentrations and relatively high organic loadings, high mass transfer characteristics, the ability to handle shock loads due to its mixing and dilution with recycle and minimal space requirements.

Discussion Topics and Problems:

1. Explain the working principle of Anaerobic Wastewater Treatment.
2. Explain Anaerobic microbiology.
3. Differentiate between Aerobic and Anaerobic treatment processes.
4. Discuss the advantages and disadvantages of anaerobic treatment.
5. Discuss the various Anaerobic Suspended Growth Processes and Attached Growth Anaerobic Processes.
6. With a neat sketch explain the working of UASB.
7. Explain the working of septic tank.
8. Design a septic tank for a population of 300.
9. Design UASB for the following data

   Flow rate = 1000 m^3/d

   COD (Influent) = 3000 g/m^3

6

Effluent Disposal

6.1 INTRODUCTION

Effluent is the supernatant water coming out of secondary settling tanks (after Trickling Filters and aeration tank of Activated Sludge Process), Septic tanks and Sludge digesters. While the effluent from Aerobic processes as Activated Sludge Process and Trickling Filters is less offensive, has low BOD and suspended solid content, that from septic tank may have a BOD of 50 mg/ℓ or more and that from Anaerobic Sludge Digester may have as high BOD as 5000 to 10000 mg/ℓ or more. Hence all the effluents cannot be treated equally and their modes of disposal vary from source to source.

6.2 METHODS OF DISPOSAL

I. Application on to land
II. Dilution into rivers and streams
III. Municipal and Industrial use

(I) Land Application:
i. Irrigation
ii. Ground water recharge
iii. Recreational lakes
iv. Natural evaporation

i. **Irrigation:** Fresh river or well water may have very low BOD, but has no nutrients in it. Effluent (of domestic sewage) contains almost all the nutrients required for crop growth in soluble form. However, the effluent need be chlorinated before being used for irrigation. The vegetables grown should not be consumed in raw state.

ii. **Ground water recharge:** Water is a must for the growth of any life. Demand of water is rapidly increasing day by day. Hence ground water table is getting lowered. Scanty and irregular rainfall may not be adequate at a place. It is to be additionally recharged. Effluent from Aerobic treatment is ideally suited for it. It can be done by storing the effluent in earthen tanks causing infiltration into strata below.

iii. **Recreational lakes:** Chlorinated effluent may be stored in artificial lakes used for the propagation of fish and other aquatic life. The lakes may also be used for boating. Partly treated sewage effluents can be used for the cultivation of Water Hyacinth which removes BOD and heavy metals, but grows very fast, clogs and ruins waterways. Besides they become the breeding centres for mosquitoes.

iv. **Natural evaporation:** When no other means of ground disposal is possible huge shallow tanks are constructed in tropical countries. A part of effluent water collected undergoes evaporation and goes into skies as vapour and another part trickles and recharges aquifer below. Temperature, wind velocity, humidity and number of sunny days in a year control the extent of evaporation. Alternate arrangements are to be made during monsoon months when the rate of rainfall is greater than evaporation and percolation rates.

v. **Dilution into rivers and streams:** A river or stream with currents has greater self purification characteristics and can assimilate the effluents. However, the effluents should be free from unsightly floating matter, and oils and greases. A minimum dilution ratio of 150 should exist in all seasons of flow of the river. After dilution, the river should have (a) a minimum flow of 100 to 200 ℓ/s per 1000 people. (b) a minimum DO of 3 mg/ℓ any time after dilution.

vi. **Municipal use:** The effluent water can be used for road cleaning, nourishing of public gardens and as recreational fountains in public places.

vii. **Industrial use:** Industries can use the effluent water for floor washing, for steam generation and as cooling waters.

Table 6.1: General standards for discharge of effluents

S. No.	*Parameter*	*Standards*			
		Inland surface water	*Public sewers*	*Land for irrigation*	*Marine coastal areas*
1.	Suspended solids, mg/ℓ	100	600	200	100
2.	Dissolved solids, Max mg/ℓ	2100	2100	2100	—
3.	pH	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0	5.5 to 9.0
4.	Temperature, Max °C	Shall not exceed 40 at any section of the stream within 15 metres down stream from the effluent outlet	45 at the point of discharge	—	45 at the point of discharge
5.	Oil & Grease, Max mg/ℓ,	10	20	10	20
6.	Biochemical Oxygen Demand (5 days at 20°C), Max mg/ℓ	30	350	100	100
7.	Chemical Oxygen Demand, Max mg/ℓ	250	—	—	250
8.	Chloride (as Cl), Max mg/ℓ	1000	1000	600	—
9.	Fluoride (as F), Max mg/ℓ	2.0	15	—	15
10.	Sulphate (as SO_4), Max mg/ℓ	1000	1000	1000	—
11.	Sulphide (as S), Max mg/ℓ	2.0	—	—	5.0
12.	Ammonical nitrogen (as N), Max mg/ℓ	50	50	—	50
13.	Total Kjeldahl nitrogen (as N), Max mg/ℓ	100	—	—	100
14.	Pesticides	Absent	Absent	Absent	Absent
15.	Phenolic compounds (as C_6H_5OH) , Max mg/ℓ	1.0	5.0	–	5.0

(*Source:* Chapter X, Environmental Standards, Handbook of Environmental Laws)

7

Sludge Treatment

7.1 INTRODUCTION

Sludge is the viscous sediment collected at the bottom of various treatment units as Secondary settling tanks after Trickling Filter, Activated Sludge Process and in a Septic tank. It is rich in organic matter, moisture and bacteria. Sludge treatment costs 40-60% of the total treatment cost of the sewage and more than 50% of cost of operation. Based on the clarifier from which it is delivered out sludge is classified as *Primary sludge* from the primary settling tank, which comprises inorganic solids and coarser organic solids of granular and dense nature (Sp.gr-2-2.5) and *Secondary sludge* from the secondary settling tank which is rich in organic matter and biological solids (bacterial cells). In the (secondary) biological reactors additional solids are generated by the conversion of dissolved organic matter into microbial cellular material. Secondary sludge is primarily composed of biological solids of sp.gr.1.2 to 1.3. In general the domestic sludge contains 92 to 98% of moisture and putrescible organic substances. The high organic contents of the sludge demands further treatment prior to its final disposal either onto land or into the sea.

Table 7.1: Composition of sludge

Matter	%	*Description*
Free water	70-75%	Separable by S*edimentation*
Floc water	20-25%	Trapped in the interstices of floc particles, separable by *Mechanical Dewatering*
Capillary water	1-2%	Separable by *Compaction*
Bound water	1-2%	Within bacterial cell, separable only by *Destruction* of cell wall
Solids of cell	0.5-1.5%	—

7.2 SLUDGE TREATMENT

Sludge treatment may include all or a combination of the following unit operations and processes as

i. Thickening
ii. Digestion
iii. Conditioning
iv. Dewatering, and
v. Incineration

i. *Sludge thickening:* It is the process of concentrating the solids of sludge to reduce their volume. Sludge collected in the tank gets stratified into upper *zone of clear liquid* (fully watery and contains no solids), intermediate *zone of sedimentation* where the solids settle and bottom *thickening zone* of dense sludge.

ii. *Gravity thickening:* Gravity thickeners increase the specific gravity of the sludge and decrease their volume to 1/3 to 1/8 of their original volume depending on the nature i.e. whether it is primary sludge or secondary sludge. It is carried out in circular sedimentation tanks. Mass of the sludge is compressed by additional layers added at the top. Water from sludge gets released and flows up. Revolving deep trusses with vertical pickets are provided in the thickening zone to gently stir the sludge blanket and move dislodged gases and liquids towards the surface.

Design particulars:
Side water depth – 3 to 4m
Detention period – 24h
Hydraulic loading – 10 to 30 $m^3/m^2.d$

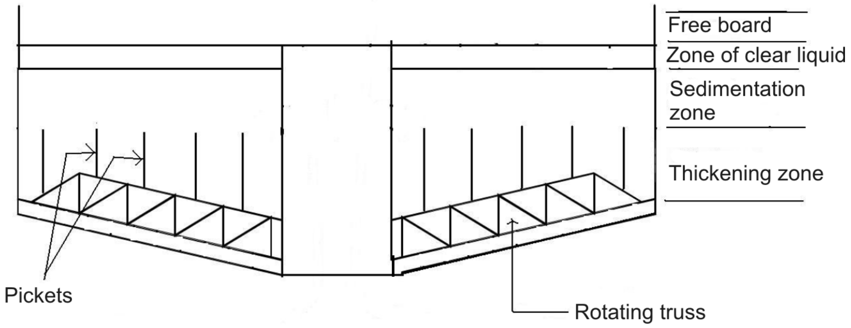


Fig. 7.1: Gravity thickener

iii. *Dissolved air flotation:* Sedimentation is the downward settling of heavy particles to the bottom of the tank. Flotation is the upward travel of lighter and finely divided suspended particles to the top surface of the tank. It is primarily used in chemical treatment and to treat activated sludge. Air is dissolved into the raw sludge under a pressure of many atmospheres. Separation of solids takes place by introducing fine air bubbles into the sludge. The bubbles rise and cause flotation of solids. The pressurized flow is discharged into a flotation tank operating at 1 atmosphere pressure. Coagulants as alum and salts of iron are added to hasten flotation. Dissolved air flotation removes the solids rapidly which otherwise settle slowly under gravity thickening.

iv. *Sludge stabilization (Sludge digestion):* Sludge digestion is the process of decomposition of organic matter into relatively stable end products with considerable reduction in volume, less obnoxious, more mineralized, thick and readily disposable end products being given out. It is done to (i) control the potential for putrification of organic matter and to reduce BOD considerably, (ii) readily dewater and easy to dry, (iii) reduce pathogens, (iv) recover useful end products as methane, (v) reduce volume of sludge.

Sludge stabilization can be biological, chemical or physical.

7.3 BIOLOGICAL STABILIZATION

Anaerobic digestion: Anaerobic digestion is one of the oldest processes used for the stabilization of sludges. It involves the decomposition of organic and inorganic matter in the absence of oxygen. In the anaerobic digestion process, the organic matter is biologically converted to methane and carbon dioxide. The process is carried out in an air tight reactor. Sludges are introduced continuously or intermittently and retained in the reactor for varying periods of time. The digested sludge is stable, inoffensive, low in pathogens and suitable for soil conditioning.

The reaction involves two stages:

(i) Complex organic matter is broken down by Acid forming saprophytic bacteria (facultative anaerobic bacteria) into short chain volatile fatty acids as acetic acid, butyric acid and propionic acid called – *Liquifaction*.

(ii) They are in turn converted into gases (i.e. $CH_4 + CO_2$) by methane forming bacteria called – *Gasification.*

Factors controlling digestion:

(i) *Temperature:* Most of the digesters operate in *Mesophilic* range (33° to 37°C) while *high rate* digesters operate at *Thermophilic* range (45° to 60°C).

(ii) *pH:* 6.5 to 8 is ideal for all bacteria. Methane bacteria are highly sensitive to pH fluctuations and cannot survive below a pH of 6.

(iii) *Nutrients:* While domestic sludge is rich in carbohydrates (COH) it lacks in Nitrogen (N), Phosphorous (P) and Sulphur (S) which are essential for the nourishment of microbes. They are to be supplemented.

(iv) *Nature of operation: Batch operation or Plug flow operation* where a batch of sludge is permitted to undergo digestion completely, the digester is emptied and then only another batch of sludge is loaded into the digester.

Continuous operation: Fresh sludge is intimately mixed with old sludge. Old sludge acts as addition of inoculating organisms for the incoming fresh sludge. Also the pH goes nearer to neutral as fresh sludge is alkaline and pH falls with the age of sludge. Bacteria being microscopic may easily get segregated because of density. But they are uniformly distributed in continuous operation leading to better efficiency.

7.4 TYPES OF DIGESTERS

Two types of digesters are now in use: (i) Standard rate digester and (ii) High rate digester. In the standard rate digestion process the contents of the digester are neither heated nor mixed. Detention times for this process vary from 30 to 60 days depending on the atmospheric temperature. In a high rate digestion process the contents of the digester are heated and completely mixed. The required detention time is 15 days or less. A combination of these two basic processes is known as the two stage process.

(i) Standard rate digester: It is a single digester where digestion, thickening and supernatant formation are carried out simultaneously in the same tank. It usually works in *mesophilic* range. Due to stratification and lack of intimate mixing about 50% of the digester volume is only effectively utilized.

(ii) High rate digester: High rate digesters are designed to operate in the *thermophilic* range. The contents are thoroughly mixed and because of it the old sludge rich in *microorganisms* (responsible for digestion) inoculates the raw sludge rich in *food*. Also

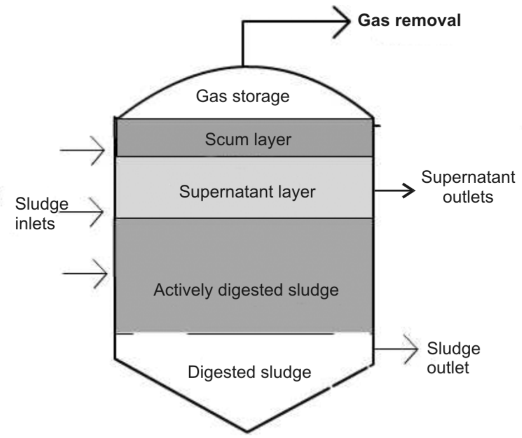


Fig. 7.2: Standard rate digester

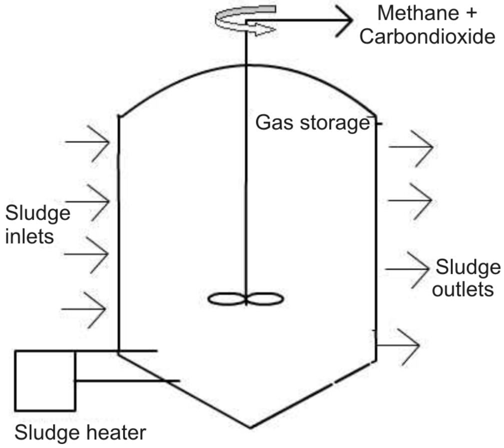


Fig. 7.3: High rate digester

fresh sludge of high pH neutralizes the fall in pH of *old sludge* because of acidification during digestion which may inhibit further biological reactions if left to itself, as in a batch reactor.

The main advantages of operating in the *thermophillic* range are the improved efficiency and improved de-watering.

The loading rate is increased

i. by continuous and intimate mixing of the sludge and hence no possibility of stratification, maintains intimate contact between feed sludge and active bio mass and creates physical, chemical and biological uniformity of the contents of the digester.
ii. by heating the sludge, the digestion period is reduced.
iii. by keeping the operation continuous.

(iii) Two stage digester: In the two stage digestion, the primary tank is a high rate digester exclusively meant for digestion where intimate mixing, heating and gas collection are done. The secondary tank acts as a storage tank where stratification occurs. Clear supernatant gets separated from the digested sludge. Little amount of gas is produced in the second digester. Generally two stage digestion is adopted when the sludge volume exceeds 4.5 MLD.

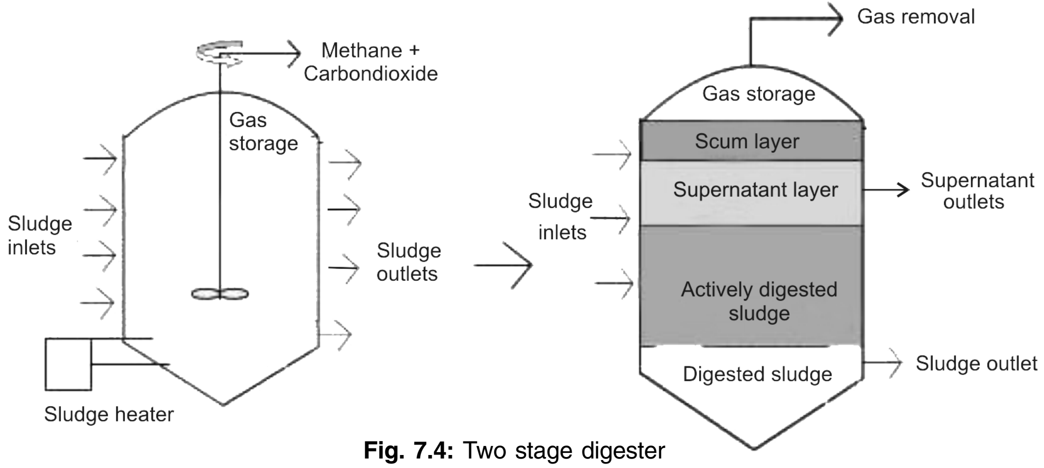


Fig. 7.4: Two stage digester

Disadvantages of Anaerobic Digestion:

i. The process is highly sensitive to pH fluctuations
ii. Poor quality of supernatant is produced at times
iii. Initial cost is quite high.

7.5 AEROBIC SLUDGE DIGESTION

Aerobic sludge digestion is *aerating* or supplying *dissolved oxygen* to the sludge undergoing active digestion. It is mainly confined to treat (i) wasted activated sludge, (ii) mixture of ASP, TF and primary sludges, and (iii) sludge from small plants using extended aeration.

As practically no food is made available for the bacteria, they start consuming their *own protoplasm* to obtain energy for cell maintenance reactions. This is called *endogenous* phase (auto oxidation) and no further cell synthesis can occur. Mechanical or diffused aerators supply the oxygen required for aerobic digestion.

Only 75 to 80% of the cell tissue can be oxidized, the remaining 20 to 25% being inert (non biodegradable matter). A detention period of 10 to 12 days may be required in the conventional aerobic digestion at 20°C, whereas it is just 3 to 4 days at 45°C. Aerobic digestion is *exothermic* i.e., gives out heat which can be utilized usefully.

Advantages

i. Volume reduction in volatile solids is the same as in the case of anaerobic digestion.
ii. Supernatant has low concentration of BOD unlike anaerobic digestion.
iii. End products are odourless, humus like and biologically stable.
iv. The system is not sensitive as the anaerobic one and hence very few operational problems exist.
v. Sludge produced is mostly inert.
vi. Initial cost is low

Disadvantages

i. High operational cost.
ii. No useful end products as *methane* are given out.

7.6 CHEMICAL STABILIZATION

Sludge is treated with high doses of chlorine or compounds of chlorine or other oxidizing agents as Hydrogen peroxide and Ozone which deodourize the sludge and microbial activity is slowed down.

7.7 LIME STABILIZATION

Lime is added to raw sewage to raise its pH to 12 or higher. At this pH sludge doesn't putrefy nor create odours nor pose a health hazard. A high lime dosage for three hour *contact time* is needed for the effective pathogen kill. Microorganisms are not destroyed but their activity is slowed and sludge must be disposed of before the organic matter starts to putrefy again.

7.8 PHYSICAL STABILIZATION (HEAT TREATMENT)

It is heating the sludge to a temperature of 140°C to 240°C in a reaction vessel at a pressure of

1720 to 2760 kN/m^2 for 15 to 40 minutes. Heat coagulates the solids, breaks down the gel structure and reduces their affinity for water. The resulting sludge is sterilized, almost de-odorized and easily de-watered on vacuum filters or filter presses without the need of chemicals. It is costly and is adopted for biological sludges difficult to digest by other means. Malodorous gases are given out. Also liquid streams of high BOD are given out.

7.9 SLUDGE CONDITIONING

Sludge conditioning is the process of separation of water from sludge. The solid particles of domestic sludge are extremely fine and hydrophilic (water-loving) and hence dewatering is difficult.

Conditioning is the process of separation of *floc* water entrapped in sludge.

i. *Physical conditioning:* Elutriation: It is washing of the sludge with wash water to remove *soluble* inorganic and organic sludge compounds. Wash water of about 2 to 6 times the volume of sludge is required for effective *Elutriation*. The wash water (after elutriation) contains large amount of suspended solids. Usually wastewater effluent (from secondary settling tanks) is used for elutriation.

ii. *Chemical conditioning:* Coagulants as Ferric chloride, Copperas (Ferrous sulphate), Alum and Lime are used for conditioning of sludge. While Alum is the most common coagulant in water treatment, salts of iron (being heavier) are the most common coagulants for sludge conditioning. They neutralize the electrostatic charge of sludge solids and thereby causing their agglomeration and settling. Lime is added to raise the pH, reduce odours and assist in disinfection. The sludge so settled is granular and porous and dewaters readily.

7.10 VACUUM FILTRATION

Sludge is conveyed in a trapezoidal bowl. A rotating drum fitted with cloth shall be rotating in it so that its bottom 1/4th or 1/5th of its diameter is submerged in sludge. A suctional force of about 85 kPa is applied along the periphery of the drum so that fine solids which get adsorbed on to the belt conveyor get dried up and separated.

7.11 INCINERATION

When the sludge is dense and contains more than 30% solids of which more than half (50%) are of volatile nature then the sludge can be incinerated. But it requires an auxiliary fuel. It is a costly process and is adopted to treat industrial sludges which can not be otherwise treated.

7.12 SLUDGE DISPOSAL

Treated sludge can be dried or dumped into huge water bodies of good velocity and currents of flow.

7.13 DE-WATERING

It is the process of separation of water from sludge by *force*. The water is squeezed out while sludge solids almost devoid of water emerge out.

7.14 FILTER PRESSING

It is compressing the sludge between the two horizontal plates of filter press and applying a pressure of 700 kPa so that the water content of sludge is squeezed out and filter cake of 20 to 40 mm thick is left out. The filter cake can be used as a manure, soil conditioner or to fill low lying areas.

7.15 CENTRIFUGING

It is injecting the sludge into a tapering rotating bowl fixed with blades causing the segregation of liquids and solids.

7.16 AIR DRYING

Sludge is applied over this bed in 200 to 300 mm thick layers and allowed to dry for one week to many weeks depending on the solar insolation. Water trickles down and gets collected in perforated drains while a part of the water gets evaporated due to air currents. Sludge cake formed over the beds is separated when got dried.

7.17 DUMPING INTO SEA

Wet digested sludge may be dumped into huge water bodies with powerful currents as perennial rivers and oceans to cause high dilution and effective homogeneous dispersion.

Discussion Topics:

1. In a comprehensive industrial waste treatment what types of sludges are created and how are they treated and disposed ?
2. Explain Biological stabilization and factors controlling digestion.
3. Explain the influence of pH on anaerobic digestion.
4. Explain with a neat sketch details of standard rate and high rate digesters.
5. Discuss aerobic sludge digestion in detail with conditions under which it can be adopted with advantage.

8

Solid Waste Management

8.1 GENERAL

Waste is an unwanted substance. Wastes are invariably produced during day to day activities. Depending on their physical state they are classified as Solid wastes, Liquid wastes and Gaseous wastes. Refuse sanitation or Solid Waste Management is the process of collection, transportation and disposal of solid waste in a systematic, economic and hygienic manner.

8.2 (A) CLASSIFICATION OF SOLID WASTES BASED ON THEIR SOURCES OF ORIGIN

Solid wastes are classified as

(i) *Residential wastes:* generated from domestic operations in a house as vegetable peels, leftover food, pieces of wornout plastics, rags of clothes, waste papers, ashes etc.

(ii) *Commercial wastes:* from business establishments as pieces of glasses, metals, ashes and food wastes from restaurants, markets, hotels etc.

(iii) *Institutional wastes:* from schools, colleges, hostels, offices which comprise paper, plastics, glasses etc.

(iv) *Municipal wastes:* arising from street cleaning and maintenance of parks. They include dust, leafy matter, building debris, treatment plant residual sludge and building demolition and construction wastes.

(v) *Industrial wastes:* arising due to industrial activities. They vary widely from industry to industry. They range from inert wastes to hazardous end products.

(vi) *Agricultural wastes* as agricultural remains, spoiled food grains and vegetable peelings.

(B) CLASSIFICATION BASED ON PHYSICAL NATURE

(i) *Garbage:* It is semi solid waste resulting from handling, sale, storage, preparation, cooking and consumption of food of vegetable and animal origin. They contain putrescible organic matter giving out obnoxious odour with time.

(ii) *Ashes and residues:* These are residues of combustion resulting from the burning of wood, coal, coke and other combustible materials. They are black fine powdery and dusty inert solids rich in carbon content.

(iii) *Combustible and non-combustible wastes:* They are inert wastes of households, community and commercial activities. Pieces of paper, cardboard, plastics, leather, textile and rubber which are combustible and give out very less ash are of one type. Non-combustible wastes of materials as tin and aluminum cans, ferrous and non-ferrous material, broken glass, house sweepings as sand are the other type.

(iv) *Demolition and construction wastes:* Demolition of existing structures give out bulky wastes of varied nature as earth, stones, concrete, bricks, ceramics, roofing and plumbing materials, heating systems and electrical wires etc. and a mixture thereof. Wastes are also generated during construction of buildings but they are less in quantity and of uniform nature, as dust of bricks, cement etc.

(v) *Hazardous wastes:* Hazardous wastes are toxic, corrosive, reactive or ignitable and hence are to be carefully preserved and separately disposed of.

Table 8.1: Classification of solid wastes

S. No.	*Type*	*Description*	*Sources*
1.	Garbage (Biodegradable food wastes)	Residual vegetable or animal wastes resulting from the handling, preparation, cooking and eating of foods. They are putrescible, and decompose rapidly, especially in warm weather.	Houses, Hotels, Dairies, Meat stalls etc.
2.	Rubbish	Combustible solid wastes, as paper, cardboard, plastics, textile, rubber, leather, wood, furniture and garden trimmings. Noncombustible solid wastes as glass, crockery, tin cans, ferrous and non ferrous metals, dirt and construction wastes	Households, Offices, Hotels, Markets etc.
3.	Ashes	Residues remaining after the burning of wood, coal, coke and other combustible wastes. They are composed of fine, powdery and dusty matter, cinders, clinkers and small amounts of burned and partially burned materials.	Fire places and Kitchens of houses, hotels, hostels etc.
4.	Demolition and construction wastes	Inert wastes such as dirt, stones, concrete, bricks, pieces of plumbing and heating and electrical parts	Demolition and Construction of buildings
5.	Industrial wastes	They are specific for a specific industry. Their characteristics vary widely as inert, highly biodegradable, toxic, reactive, odorous, corrosive, hot, cold, coloured, viscous, inflammable and dusty.	Different types of Industries, Thermal power plants etc.
6.	Hazardous wastes	Solid wastes from communicable disease hospitals, explosives, radioactive materials etc.	TB sanitoriums, explosive, and pesticide industries etc.

8.3 PROPERTIES OF SOLID WASTE

(A) Physical properties:

(i) **Particle size:** Particle size is the size of the biggest particle in a lump. Smaller the particle, difficult is its collection, conveyance, handling and segregation. However smaller organic matter has greater surface area and hence decomposes quickly.

(ii) **Moisture content:** It is the percentage of moisture retained by the solid waste of unit weight. Moisture content of solid varies very widely i.e. from 10% to 90% depending on the nature of waste, precipitation, environment and climatic zone.

Table 8.2: Typical composition, moisture content and density of municipal solid waste of an Indian city

Components	*Mass % range*	*Moisture content % range*	*Density in kg/m^3 range*
Paper	15-45	4-10	30-130
Food wastes	6-26	50-80	120-480
Glass	4-16	1-4	160-480
Cardboard	3-15	4-8	30-80
Plastics	2-8	1-4	30-130
Tin cans	2-8	2-4	45-160
Wood	1-4	15-40	120-320
Ferrous metals	1-4	2-6	120-1200
Textiles	0-4	6-15	30-100
Leather	0-2	8-12	90-260
Non ferrous metals	0-1	2-4	45-160
Rubber	0-1	1-4	90-200
Dirt, ash etc.	0-10	6-12	320-960

Greater moisture content increases the weight of solid waste and hence cost of collection and transportation. Segregation of waste slows down because of greater moisture content. Cost of incineration increases with moisture content.

However biological degradation hastens with percentage of moisture. Chemical and biological reactions are accelerated due to the presence of moisture.

(iii) **Density:** Density is the weight in 'kg' of 'cubic metre ' of solid waste in normal (i.e. loose and not compacted) state. Greater the density less is the volume occupied and easier is the collection, transportation and handling. Density of solid waste in a landfill after repeated compactions may rarely exceed 600 kg/m^3.

(B) Chemical properties:

Chemical nature of the solid waste governs its method of disposal.

Classification: Solid wastes may be

(i) **Inert:** as building demolition wastes whose volume remain the same irrespective of time. No gases of decomposition emanate out of them.

(ii) **Degradable:** undergoing decomposition or degradation physically, chemically or biologically. Their volume reduces with time. Gases of decomposition are given out.

Carbohydrates: They are mostly found in solid wastes from underdeveloped and developing countries. They are starches and cellulose of composition and principally contain carbon, oxygen and hydrogen. They readily decompose to give out carbondioxide and water and also methane under anaerobic conditions. Flies and rodents are easily attracted towards decomposing carbohydrates and hence they should be properly protected.

Proteins: $(COHN)_X$ is their general composition i.e. they have nitrogen in addition to carbohydrates. They constitute major portion of wastes from affluent countries but relatively less in poorer countries. They decompose slowly compared to carbohydrates and offensive odours as ammonia are given out in addition to CO_2, CH_4 and water vapour.

Lipids: Lipids are fats, oils and greases and mainly contain carbon, oxygen and hydrogen. They are slow to degrade. They have very high heating values of around 38,000 kJ/kg.

Fibres: of vegetable origin as those from coconut shells, bamboo, sugar cane etc., are of cellulose and lignin. Papers and rags are the common sources of fibres. They are very resistant to biological degradation but are readily combustible. yielding 12,000 to 20,000 kJ per kg.

Plastics: are synthetic organic materials, highly resistant to biodegradation and hence are highly objectionable. They constitute 1 to 10% of the total volume of solid wastes and this percentage is rising from year to year.

They have high heating value to the tune of 30,000 kJ/kg of plastics, but give out odourous and acidic gases responsible for corrosion and acid rain. Separating them out to recycle plastics is the best solution.

Another classification of municipal solid waste is

(i) Ignitable: can readily catch fire as dry leaves and paper leaving small amount of ashes. Energy content is expressed as kilojoules per kilogram (kJ/kg) of solid waste. It is determined by measuring heat generated in a Bomb calorimeter at a temperature of 25°C from the combustion of a dry sample of solid waste.

(ii) Needs auxiliary fuel for combustion as in case of green wastes, carcasses and

(iii) Can not be easily destroyed by heat of reasonable intensity as glass, ceramics, metals and ashes.

Other classification is

(i) Reactive i.e. acidic or alkaline solid wastes.

(ii) Hydrophilic solid wastes absorbing water as in case of cement dust etc.

8.4 FACTORS INFLUENCING SOLID WASTE MANAGEMENT

(i) **Per capita income and status:** Higher the income more is the quantity of solid waste produced. 0.25 to 2.5 kg/capita/day is roughly the quantity of municipal solid waste produced in India. More is the quantity of waste greater is the content of paper and packing materials.

(ii) **Climate and percentage moisture:** While the percentage of moisture is less than 50% in summer months, it is more than 65% in wet weather. It is easy to collect and transport solid wastes in dry climate and collection and handling are difficult in wet weather. Quantity of leachate is less during dry weather and is more during wet weather. Decomposition is accelerated with increase in moisture and temperature. Hence clearing interval (of solid wastes) is smaller in hot and humid climate while it can be longer in cold and dry climate.

(iii) **Systematic growth of city:** A planned town of wide roads and stream lined growth of houses facilitates easy collection of refuse and hence bigger or smaller containers at regular intervals for refuse collection may be provided. An irregularly grown old town or outskirts of a town with ribbon development pose problems of collection. Hence smaller containers at closer intervals need be provided as the lanes are narrow and of irregular alignment.

(iv) **Status of the municipality:** The income, expenditure and funds to be allotted for street cleaning and disposal of solid wastes do influence the method. A rich municipality can afford more spending on solid waste management. It can maintain a crew of permanent employees and fleet of vehicles involved in collection, transportation and disposal of the solid waste (i.e. for compaction). It can own disposal sites. A poor municipality has to hire the crew and trucks for transportation on a temporary basis. It has to take disposal sites on temporary lien.

(v) **Customs and practices:** Customs differ from community to community and from street to street of a town. A posh locality may contribute more solid waste but almost of the same nature. Middle income group residences may contribute solid wastes of quite diversified natures.

(vi) **Resources available:** Based on the technical skills of skilled persons available, unskilled men and women labour available, the extent of site available for disposal of wastes, one should arrive at optimum utilization of their services to get the best desirable outcome.

8.5 SOLID WASTE MANAGEMENT

To assess the management possibilities it is important to consider

(i) origin of solid wastes
(ii) reduction in raw materials usage
(iii) reduction in amount of solid waste
(iv) reuse of waste materials
(v) salvaging.

(i) **Origin of solid wastes:** Solid wastes are generated at different stages as
(a) extraction of raw materials i.e. mining as in metallurgical processes or crop extraction as sugar cane cutting in sugar industry or bamboo cutting in paper production.
(b) every stage of operation – converting raw materials into the finished product.

(ii) **Reducing quantity of raw materials:** It can be achieved by better techniques as
(a) condemning the old machinery whose efficiency is low
(b) improving the output by adopting better technology.

(iii) **Reduction in quantities of solid wastes:** It can be done by reusing or recycling some of the wastes generated so that the quantity of waste generated is considerably reduced per tonne of the product produced.

(iv) **Segregation and recovery:** Segregate the solid waste to extract valuable products as metals. Even inferior wastes as "*Baggasse*" in a sugar mill can be utulized as a fuel to generate steam in industrial operation or for the preparation of pulp in paper making. Fibres of coconut can be used in coir industry.

(v) **Salvaging:** Food content of organic matter can be effectively used as hog feed or poultry feed. Similarly good manure can be extracted from domestic solid wastes.

Management of municipal solid wastes involves Collection, Transportation, Storage, Processing and Disposal.

8.6 ENGINEERED SYSTEMS FOR SOLID WASTE MANAGEMENT

The activities associated with the management of solid wastes from the point of generation to final disposal can be grouped into 5 operations:

(i) Waste collection into dust bins
(ii) On-site handling, storage and processing
(iii) Transportation
(iv) Processing and
(v) Disposal.

8.7 WASTE COLLECTION INTO DUST BINS

Solid and Semi solid waste matter is to be emptied into dust bins provided by the Municipal authorities. These dust bins may be fully covered or partly open so as not to attract insects and stray dogs. They should be of adequate capacity to retain solid wastes (without any spreading outside) in between the definite intervals of clearing i.e. capacity of the dust bin must be more than the waste generated. No resident invites a dust bin nearer to him (NIMBY Syndrome = Not in my back yard) and at the same time wishes it not to be far away from his house. People may throw their refuse any where and every where if the dust bin is far off. Hence the municipal authorities should fix the positions of dust bins for effective collection. They should prevent private refuse collectors from stepping into the bin as their tendency is to collect selected waste as papers and rags and spread the waste over a vast area outside the bin and a stray dog is better than them in less polluting the neighbouring area of the dust bin.

(a) Location of the street
(b) Density of population
(c) Frequency of cleaning the dust bin
(d) Attitude of the residents
(e) Season
(f) Tendency of the people to salvage or recycle or adoption of other methods to reduce volume of refuse
(g) Law enforcing nature of municipality and law abiding tendency of the locals
are the various factors influencing the quantities of solid wastes collected into dust bins.

Types of Bins: These dust bins can be
(i) stationary type – whose particulars are mentioned above and
(ii) hauled type: closed containers mounted on trucks which collect refuse from each and every house of the street. The house owners retain their solid wastes in their private bins and they empty them into the hauled type of container. Hauled types of bins can be conveniently adopted in densely populated residential areas where it is impossible to locate and operate stationary type of bins. The origin of the type of waste can be easily identified quantity of waste generated is also relatively less in hauled type of bins. However stationary type bins need be located to collect street sweepings and refuse of passers by as peelings of fruits and wrappers of eatables in addition to hauled type bins.

8.8 ON-SITE HANDLING, STORAGE AND PROCESSING

This includes sorting, compaction and incineration of the contents of the dustbin so as reduce the volume of refuse to be transported for final disposal.

(a) Method of collection of refuse
(b) Size, shape, material and type of dust bin provided
(c) Location of the dust bin and
(d) Environment and aesthetics
are the factors governing on site handling.

8.9 TRANSPORT

The contents of the dustbins are emptied into bigger trucks and these trucks haul the solid waste to the place of disposal. Transport is the costliest of all the operations and should be carefully planned. The trucks should be of closed type. If of open type they must be covered and hauling through busy streets should be done during lean traffic hours and preferably at night so as to prevent the spread of foul smells of refuse.

8.10 PROCESSING

Processing is the segregation and sorting out of the solid wastes to

(a) recover materials which can be put to use as pieces of wood, metal scrap, paper, glass, plastics etc.
(b) segregate solid waste that can readily burn to give out ashes from other which is not affected by heat
(c) separate biodegradable matter from inert matter that may not decompose even after considerable period
(d) salvage organic matter which can be used in the preparation of hog feed and poultry feed.

Processing also involves mechanical compaction which reduces its volume considerably.

8.11 DISPOSAL

i. Land disposal
ii. Sanitary landfilling
iii. Composting
iv. Incineration

8.11.1 Land Disposal

It is a non-engineered disposal method. It is uncontrolled dumping of the solid waste on the surface of earth. Low lying areas far away from human habitation are generally used for this purpose. Inert inorganic waste as that of demolition and construction waste is ideally suited for the filling of low lying areas.

As it is the cheapest most of the municipalities are resorting to this. But lighter solid wastes spread over a vast area, create unsightly conditions. The ground breeds, flies and rodents. Foul smells emanate out of decomposing wastes. Hot ashes may cause burning and smoke production of the solid wastes associated with undesirable odours. Hence the method is hygienically and aesthetically undesirable.

8.11.2 Sanitary Landfill

It is a systematic engineering operation of dumping the solid waste at the site of disposal, compacting it and covering it with a layer of earth so as to be in conformity with the neighbouring natural land. It relies more on containment of the contaminant of waste than the treatment of solid wastes.

Various stages involved in sanitary landfilling are (a) selection of site, (b) method of land filling and (c) control, collection and regulation of gases and leachates generated.

(a) Selection of site:

i. *Location:* The site should be away from human habitation and preferably located on the leeward side of the city taking into account the wind-rose diagram of summer months.

ii. *Topography:* A low lying area is preferred. If no such site is available, the site is rendered to receive solid waste filling. Run off from the site should never get collected in natural courses of water.
iii. Area of the site should be such that it should permit easy dumping of solid waste over it for more than a year.
iv. *Subsoil:* The subsoil should be impervious or less porous. Porous soil to be used as cover for the landfills after compaction must be available at or near the site.
v. *Groundwater table:* Ground water should not be available at shallow depths.
vi. *Climate:* Hot and dry climate is quite preferred to wet climate. Rainfall of the area should be less.
vii. *Environment:* The area, though well connected to the roads for easy transportation, should be separated from the land of human activities as agricultural lands by rows of trees or by a compound wall constructed to enclose the area. Its neighborhood should be free from pollution and preferably of lushly vegetable growth.
viii. *Distance of haul:* The site should not be quite far off as the length of transport and hence cost of operation of the solid waste disposal is going to increase.
ix. *Ultimate use of the site:* When the site gets filled up and can no more take any load (after many years), to what use the site is going to be put is to be decided now itself and strictly adhered to in future.

(b) Land filling methods: Depending on topography and environmental conditions the land filling methods are:

i. *Depression method:* It is made use of when a natural or man made depression is available at a convenient place. Waste is spread over the area in thin layers and well compacted. Another layer is added above. At the end of day's operation 150 mm thick earth layer is laid and covered and compacted on all sides. Thus a unit of solid waste is to be enclosed on all sides by an earthen cover.
ii. *Trench method:* When no depression is available, trenches are dug and the earth excavated can be used as covering material.
iii. *Area method:* When neither a depression exist nor it is possible to dig trenches, area method is used. The site should be enclosed on all sides with tall embankments. Cell over cell is added until the compacted waste reaches a height of 2 to 3m.
iv. *Cell method:* Instead of dumping the solid waste over a vast area, filling, compaction and covering it with a layer of soil is done in a smaller area and the unit so formed is called 'a cell'. Cell is a definite unit confined on all the sides and is heterogeneous in composition. It is a better method than any other method of land filling because of independent cells of less area and volume and ease of handling.

Municipal solid waste is dumped into the pit and compacted. Settlement of MSW occurs with time. The settlement can be classified as

(a) Primary consolidation occurs due to the weight of the waste, weight of moving trucks and compactors and squeezing out of the moisture content of the solid wastes.
(b) Secondary consolidation occurs very slowly compared to primary consolidation as there is a limit for mechanical compaction and reduction in the moisture content.
(c) Consolidation due to decomposition of organic matter takes place anaerobically because of
    i. conversion of solid wastes to volatile fatty acids and alcohols
    ii. conversion of alcohols to acetic acid and hydrogen
    iii. conversion of acetic acid and hydrogen to methane and carbon dioxide.

Consolidation due to decomposition will be considerable due to the liquification and gasification of solid wastes resulting in leachates and landfill gases.

$$\underset{\substack{\text{[carbohydrates}\\ \text{of MSW]}}}{C_6H_{12}O_6} \xrightarrow{\text{Anaerobic bacteria}} CH_4 + CO_2 + \text{Heat} + \text{New anaerobic cells}$$

(c) Leachates: Solid wastes of a landfill undergo decomposition and decay. They undergo physical, chemical and biological changes. Liquids emanated out of the waste are called *'leachates'* which percolate horizontally or vertically. The volume of the leachates increases because of drainage or sub surface water mixing with it. Downward percolation of leachates can be prevented by providing liners. These liners can be of *'plastic clay'* or synthetic ones as *'membranes'*. Membrane liners are costly and are easily damaged.

(d) Gases: Gases mainly as methane, carbon dioxide, hydrogen sulphide, ammonia and carbon monoxide are given out from sanitary landfills due to anaerobic decomposition of organic wastes. More than 90% of the total gases are methane and carbon dioxide.

Vents at regular intervals may be provided to clear off the gas accumulations. Otherwise they are ejected out through the line of least resistance and at times may cause fire hazards and explosions. (Methane is inflammable and is the main constituent of cooking gas). If confined, the gas may travel laterally through considerable lengths.

(e) Land Farming: Finely divided biodegradable organic matter as domestic sludges or even oily ones as petroleum sludges can be effectively disposed of by land farming. The wastes are either applied at the surface or injected into the layers below. Depending on the type of soil, position of groundwater table, type of crops to be raised nutrients may be supplemented to get good yield of crop.

8.12 COMPOSTING

More than 70% of the Indian municipal solid waste contains organic materials. Industries as paper, agricultural and food processing give out wastes which are almost 100% organic. This organic matter can be *composted* to yield good manure. Compost is the end product obtained after subjecting the organic fraction of solid waste to aerobic or anaerobic decomposition to yield humus like solid, carbon dioxide, water vapour and energy.

$$\text{Organic matter} + O_2 \xrightarrow{\text{Aerobic bacteria}} CO_2 + H_2O + NH_3 + \text{energy} + \text{other end products}$$

$$\text{Organic matter} \xrightarrow{\text{Anaerobic bacteria}} CH_4 + CO_2 + H_2O + NH_3 + H_2S + \text{energy} + \text{other end products}$$

Different Stages of Composting:

i. *Segregation of solid waste:* Non-compostable materials such as glass, plastic, paper, rags, rubber, metal and leather are separated from the solid waste.

ii. *Processing the compostable matter:* Compostable matter is cut to small pieces by shredding, pulping or grinding.

iii. *Preparation for compost:* Moisture content is maintained between 45 to 55% (by weight) and carbon to nitrogen ratio should be less than 30.

iv. *Digestion:* (Indore Method-Aerobic): The organic matter thus ready is put in loose heaps of diameter of 3 to 6m and height of 1.5 to 3m on an impervious ground. It is so placed that it is subjected to continuous aeration. The actual size of the heap depends on particle size, moisture content, pore space and rate of decomposition. Mesophilic bacteria decompose the waste first and during the decomposition the temperature rises above 50° C. At this temperature thermophilic bacteria take over causing very rapid decomposition. However, this stage lasts for a few days and then the compost cools. The heap is turned after 4 to 7 days and again after another 5 to 10 days.

v. *Curing:* Maturing or curing is the final phase of composting which runs through a few weeks or may be as long as a year. Curing destroys pathogens where as uncured compost may produce phytotoxins which consume oxygen and nitrogen of soil thus depriving the plants of them.

vi. *Screening:* Cured compost is screened and the coarse lumps left over are sent back to digestion.

Anaerobic Composting (Bangalore Method)

Coarse refuse in layers of 150 to 250 mm thick is placed at the bottom of the pit. It is rendered saucer like by providing additional layer of 75mm thick and 250 mm wide along the boarder. Night soil as 50 mm thick layer is spread over the central depressed portion and the second layer of refuse is laid over this. Thus alternate layers of refuse and night soil are repeated until the top layer of refuse reaches a height of 300 mm above the adjoining ground level of the pit. The top layer is rounded off and covered with a layer of clay to act as a sealing layer and prevent the breeding of flies. After 4 to 6 months compost is ready for use.

Anaerobic Digestion

It is the process of extraction of *methane* out of the solid waste. The organic fraction of the solid waste is comminuted so that fine sized particles of the solid waste are formed. It is mixed with hot water at 55 to 60 °C (Thermophilic range), nutrients as nitrates, phosphates and potash are added, pH is adjusted to be fairly above 6.5 (methane bacteria cannot survive below a pH of 6) and the contents are continuously mixed for a period of 5 to 10 days. The gas evolved is collected.

8.13 BIOREACTOR LANDFILL

It is a process accelerating the stabilization of the landfill material and increasing the evolution of more amount of gas by hastening the microbial activity. This is achieved by injecting leachate, waste water sludge, wastewater or even storm water into the layers of landfill to maintain a moisture content of 35% to 65% and to enhance microbial activity.

In aerobic process air is also made to circulate through different layers of landfill by providing interconnected horizontal and vertical wells through landfill layers. No such aeration is provided in anaerobic process and the methane generated is carefully collected as otherwise it tends to catch fire or may add to the green house gases responsible for *global warming*.

Advantage of Bioreactor Landfills:

i. Decomposition is hastened i.e. takes only years for stabilization while the period is decades in conventional landfill.

ii. Leachate is effectively used and hence its quantity gets reduced considerably, lowering the cost of treatment.
iii. Less space (i.e. 70 to 85% of that required for the conventional type) is required.
iv. Less toxic matter is left over after decomposition and pathogens are eliminated.
v. Significant quantities of methane is given out which is of immense value as a fuel.

8.14 INCINERATION

It is thermal treatment of solid wastes. It is burning of the waste at a temperature of 1000°C ± 100°C in the presence of oxygen so as to eliminate all odours and to ensure good combustion. To burn every tonne of MSW, 5 tonnes of air is required. Paper, Textiles, Plastics, Leather, Rubber, Wood and Food waste content of municipal solid waste can be burnt down to yield ashes which occupy less than 10% of the original volume of solid waste.

May be very few components of municipal solid waste as glass, metals, ceramics and ashes may not undergo much transformation because of heat but their percentage content in municipal solid waste is very less.

Combustible ingredients of municipal solid waste mainly contain carbon, oxygen, hydrogen, nitrogen and sulphur which are oxidised to carbon dioxide, water vapour, oxides of nitrogen and sulphur dioxide after combustion.

Dulong's formula

$$\text{Energy content (kJ/kg)} = 338C + 1442\left(H - \frac{O}{8}\right) + 95S$$

where
C = % carbon
H = % hydrogen
O = % oxygen
S = % sulphur

Advantages of Incineration:

i. *Reduction in volume:* Volume gets reduced considerably to approximately 1/10th of its original volume.
ii. *Harmless end products:* The residue left over after incineration is free from odours, pathogens and toxins.
iii. *Stable end products:* The ashes of combustion are sterile and inert and do not undergo any change. They are in powdery state and handling is very easy.
iv. *Only way:* Incineration is the only method of disposal of solid waste from hospitals dealing with communicable diseases like TB sanitoria. It is the effective method in deforming and disposal of secret documents and objects likely to reveal true details of secrets to the opponents.
v. *Energy recovery:* Utilisation of waste heat for the generation of steam and electricity.
vi. *Smaller site:* Incinerator occupies less area compared to any other method of disposal.

Disadvantages:

i. *Costly:* Incineration is a very costly process. Fuel or energy required for incineration shall be costing heavily to the municipality.

ii. *Affecting neighbourhood:* Land adjacent to the incinerator loses its value due to dumping of refuse, uncontrolled movement of trucks transporting the waste and due to heat radiation.

iii. *Environmental impact:* Heat, smoke, noise (due to the movement of the refuse trucks) and ash are generated by the incinerator. Hence surroundings become barren and free from vegetation. Hot ashes also add to the desert environment. Though most of the odours get dissipated at higher temperature still some arising due to the burning of plastics may give out unbearable smells (may be for a small length of time).

Mass Burning Incineration

It consists of two or three incinerators each capable of burning 50 to 3000 tonnes of MSW per day. The refuse is dried to reduce the moisture content and metal scraps and plastics are removed. Also over sized refuse is either cut to size or removed. It is then fed on to the grate where the refuse is burnt to ashes. The heat generated may be used for steam production and electricity generation.

Discussion Topics:

1. What is a compost ? Explain Bangalore method of composting.
2. Explain how recycling of certain components of municipal solid waste helps in its disposal.
3. Explain the environmental implication of incineration of municipal solid waste.
4. Describe the physical and chemical changes that take place in a landfill site during its life.
5. Write a note on typical composition of Municipal solid waste.
6. Discuss prospects in landfill gas generation.
7. What are the gases released from a typical landfill site ?
8. What are the hazardous waste constituents of Municipal solid waste in an urban area ? State their impact on environment.
9. What is the basic difference between pyrolysis and gasification ?
10. Discuss the various factors that affect the quantity and composition of landfill gas.

9

Bioremediation

9.1 INTRODUCTION

Industrial and domestic wastes are produced in the three physical states, i.e. as solids, liquids and gases.

Solid wastes pollute the soil with which they come in contact. Liquid wastes as well as *leachates* of solid wastes flow horizontally over the ground or percolate vertically into the layers below thus polluting the soil layers and ground water with which they come in contact.

Gaseous and vapourous wastes spread horizontally and vertically in the atmosphere, get washed out by rain water and ultimately reach the ground polluting the soil and water. Irrespective of their physical state i.e. whether solid, liquid or gas the waste can be classified as *biodegradable* and *non-biodegradable*. The biodegradability of a waste can be rapid, moderate or slow.

Bioremediation is the controlled degradation of soil and ground water biologically i.e. by microbes of soil to yield stable and harmless end products as CO_2 and H_2O.

Soil is the loose material of earth primarily composed of mineral fraction (Inorganic matter as SiO_2,Al, Fe and less quantities of Ca, Mg, K, Mn, Na, N,P and S) and organic fraction (plant and animal debris, microbes and *humus*). It has moisture and void space between particles where gases accumulate.

Groundwater gets accumulated in porous beds over an impervious layer and this porous bed containing water is called an aquifer.

Both soil and water form an important base for bacteria (microscopic plants) to flourish. However these microbes need be provided with nutrients as N,P & K which may be deficient in the waste as well as in soil as the soil is of varying degree of fertility (may be highly fertile or totally barren).

Of all the processes of waste treatment biological treatment is cheaper than both physical and chemical processes provided the waste is biodegradable, more soluble in water and is non-toxic to microbes.

9.2 CONTAMINATION OF SOIL AND GROUND WATER

Septic tank effluents, discharges from waste stabilization ponds, gasoline leaks from underground storage tanks contribute to the pollution of soil and ground water.

Also bursting of mobile chemical containers, accidental spills of toxins, agricultural discharges rich in pesticides, oils and cleaning solvents from garages are responsible for soil and water contamination.

Every industry contributes industrial wastes which add to the pollution of soil and ground water.

Pesticides when reach drinking water, cause nervous disorders in addition to cancers of different origin.

Continuous exposure to diesel and petrol vapours is *carcinogenic*. Paints and varnish wastes (from sanitary landfills) contribute to disorder of nervous system and heavy metal poisoning besides being carcinogenous.

Bioremediation is the conversion of these potential pollutants of soil and water of organic or inorganic nature into harmless substance by the microorganisms of the soil.

The technology to treat vaporous wastes biologically is termed as *Biofiltration*. The time taken and the efficiency of the treatment depends on the type of soil, temperature, pH and the microbial environment prevailing for the decomposition of the waste.

Depending on the type of bacteria that are responsible for the degradation i.e. in the presence of free oxygen or oxygen in combined state, bioremediation is classified as 'aerobic' or 'anaerobic'. Most of the biodegradation is aerobic as anaerobic process is relatively slow and is difficult to maintain for bioremediation process. But it is preferred where *reduction* is favoured over *oxidation* as in case of *chlorinated compounds*.

Bioremediation i.e. decomposition of waste by soil bacteria successfully used for the degradation of petroleum sludges is now being used for the biodegradation of Benzene, Alcohols, Chlorophenols, pesticides and other hydrocarbons once considered to be resistant to biodegradation.

9.3 BIOREMEDIATION SYSTEMS

9.3.1 Soil Bioremediation

In situ Bioremediation: *In situ* means "in the original place" i.e. the polluted soil is treated without shifting it from its original place. *Ex situ* is removing the soil from its place of origin for treatment.

In situ treatment is adopted where the volatile fraction is dominant (as is the case with petroleum sludges). A number of wells are driven around the contaminated site to establish and enclose the area of operation.

Extraction of the soil vapour can be done by applying a suctional force of 0.1 to 0.2 atmosphere through the suction well located in the middle of the contaminated zone (sandwiched on all sides by ventilation wells). This suction well may have a radius of influence as greatest as 10m and this radius depends on the composition of soil, amount of vacuum applied and rate of extraction of the gas or soil vapour. Gases and vapours of H_2S, NH_3, petroleum etc are extracted by this process is called *soil venting*.

When semi volatile and non-volatile fraction is dominant the process is called *bioventing*. Air is supplied to the contaminant to undergo oxidation and biodegradation microbially. The favourable environment for growth and multiplication of the specific variety of microbes is done by inoculation, oxygen and moisture supply and by supplementing nutrients which the soil and the waste to be treated is lacking in. The site of bioventing shall be small and is usually confined or enclosed by providing sheet piles. The depth is shallow.

Ex situ treatment involves excavation of the contaminated soil, transporting it to the place of disposal, mixing it with bulking agents as manure and moisture and treating by inoculating with the necessary microbes along with nutrients required for their proliferation – *'Composting'* (solid phase) and slurry phased *Bioremediation* are ex situ treatments.

9.4 GROUNDWATER BIOREMEDIATION

It is the purification of polluted groundwater either by *In situ* or *Ex situ* process. It is done by injecting oxygen (either as hydrogen peroxide or by air sparging), nutrients and (some times) microbial culture into the aquifer. The bacteria in enough numbers and under favourable conditions oxidise the pollutants within as in case of Activated Sludge Process (a suspended growth reactor) leaving out mineralised and stable end products as CO_2 and H_2O. Ex situ treatment involves pumping out of the polluted water to the place of treatment. It is more efficient but is costly. Hence it is used on a limited scale.

9.5 BIOFILTRATION

Treating of solid wastes and semi solid sludges is termed *Bioremediation*. Treatment of contaminated vapour and gases is called *Biofiltration*.

Biofiltration is the passing of the contaminated or odorous gas through a packed tower of microbes. The biofilter consists of porous grannular media of very fine size over which the microbes grow. Air and nutrients are periodically supplied for the upkeep of the microbial film. Contaminated or odourous gases are oxidised during their upward travel through the biotower and the gases emerging out are odour free and free from pollutional characteristics.

9.6 MERITS OF BIOREMEDIATION

Bioremediation is a simple, novel, recent and cheap process to deal with both organic as well as inorganic wastes in the solid, liquid and gaseous states. It can be employed even to detoxify and biodegrade hazardous wastes.

9.7 LIMITATIONS OF BIOREMEDIATION

Bioremediation is dependent on microbial activity. These microbes inturn flourish depending on temperature, pH, moisture content, nutrient availability, contaminant toxicity, contaminant concentration and oxygen available. A system may take days to stabilize and any drastic change in the above mentioned parameters may affect the efficiency of bioremediation.

5° to 40° C is the range in which soil bacteria flourish. In general as the temperature increases the microbial activity increases exponentially but a specific type of bacteria proliferates in a specific range only. Bacterial activity ceases outside this range.

Most microbes have their peak activity around a neutral pH of 6 to 9. Moulds and yeasts prefer acidic range while sulphur bacteria (Thiobacillus) prefer a pH around 1, Methane fermentors cease to act when the pH falls below 6.

While carbon, hydrogen and oxygen (carbohydrates) are available in plentiful for bioremediation process, nutrients as Nitrogen, Phosphorous and rarely Sulphur need to be supplemented. Nutrients must be applied in soluble form along with oxygen.

But when moisture content blocks the pores less oxygen is available for bioremediation. A moisture content of 15 to 25% (by weight) is ideal for flourishing of microbes.

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