UNIT 7 TREATMENT OF WASTEWATER

Structure

7.1 INTRODUCTION

Wastewater treatment is becoming ever more critical due to diminishing water resources, increasing wastewater disposal costs, and stricter discharge regulations that have lowered permissible contaminant levels in waste streams. The treatment of wastewater for reuse and disposal is particularly important for water scarce areas. The municipal sector consumes significant volumes of water, and consequently generates considerable amounts of wastewater discharge. Municipal wastewater is a combination of water and water-carried wastes originating from homes, commercial and industrial facilities, and institutions.

Untreated wastewater generally contains high levels of organic material, numerous pathogenic micro-organisms, as well as nutrients and toxic compounds. It, thus, entails environmental and health hazards, and, consequently, must immediately be conveyed away from its generation sources and treated appropriately before final disposal. The ultimate goal of wastewater management is the protection of the environment in a manner commensurate with public health and environment.

Nature of Municipal Wastewater

An understanding of the nature of wastewater is fundamental for the design of appropriate wastewater treatment plants and the selection of effective treatment technologies. Wastewater originates predominantly from water usage by residences and commercial and industrial establishments, together with groundwater, surface water and stormwater. Consequently, wastewater flow fluctuates with variations in water usage, which is affected by a multitude of factors including climate, community size, living standards, dependability and quality of water supply, water conservation requirements or practices, and the extent of meter services, in addition to the degree of industrialization, cost of water and supply pressure. Wide variations in wastewater flow rates may, thus, be expected to occur within a community.

Wastewater quality may be defined by its physical, chemical and biological characteristics. Physical parameters include colour, odour, temperature, and turbidity. Insoluble contents such as solids, oil and grease, also fall into this category. Solids may be further subdivided into suspended and dissolved solids as well as organic (volatile) and inorganic (fixed) fractions.

Chemical parameters associated with the organic content of wastewater include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) and total oxygen demand (TOD). Inorganic chemical parameters include salinity, hardness, pH, acidity and alkalinity, as well as concentrations of ionized metals such as iron and manganese, and anionic entities such as chlorides, sulphates, sulphides, nitrates and phosphates. Bacteriological parameters include coliforms, fecal coliforms, specific pathogens, and viruses. Both constituents and concentrations vary with time and local conditions.

The effects of the discharge of untreated wastewater into the environment are manifold and depend on the types and concentrations of pollutants. Important contaminants in terms of their potential effects on receiving waters and treatment concerns are briefly explained below.

Suspended solids (*SS*) can lead to development of sludge deposits and anaerobic conditions when untreated wastewater is discharged into the aquatic environment.

Biodegradable organics are principally made up of proteins, carbohydrates and fats. They are commonly measured in terms of BOD and COD. If discharged into inland rivers, streams or lakes, their biological stabilization can deplete natural oxygen resources and cause septic conditions that are detrimental to aquatic species.

Pathogenic organisms found in wastewater can cause infectious diseases.

Priority pollutants, including organic and inorganic compounds, may be highly toxic, carcinogenic, mutagenic or teratogenic.

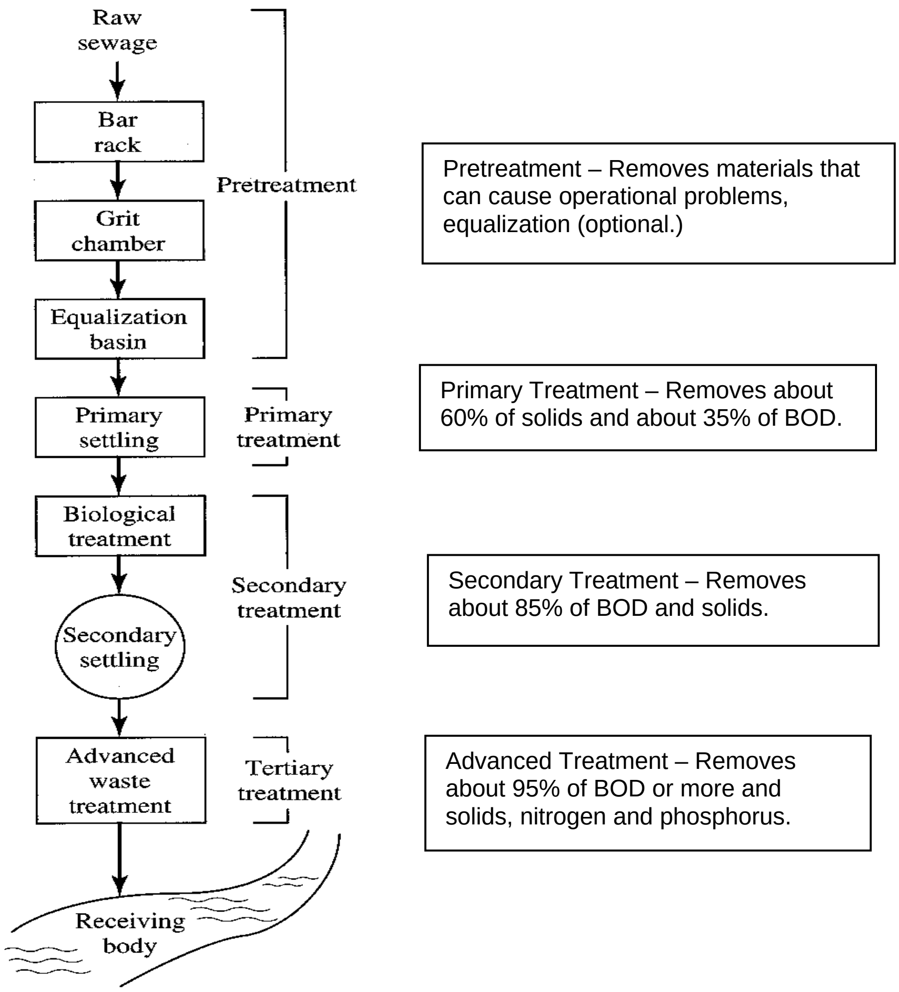
Refractory organics that tend to resist conventional wastewater treatment include surfactants, phenols and agricultural pesticides.

Heavy metals usually added by commercial and industrial activities must be removed for reuse of the wastewater.

Dissolved inorganic constituents such as calcium, sodium and sulphate are often initially added to domestic water supplies, and may have to be removed for waste-water reuse.

Overview of Wastewater Treatment Technologies

Physical, chemical and biological methods are used to remove contaminants from wastewater. In order to achieve different levels of contaminant removal, individual wastewater treatment procedures are combined into a variety of systems, classified as primary, secondary and tertiary wastewater treatment. More rigorous treatment of wastewater includes the removal of specific contaminants as well as the removal and control of nutrients. Natural systems are also used for the treatment of wastewater in land-based applications. Sludge resulting from wastewater treatment operations is treated by various methods in order to reduce its water and organic content and make it suitable for final disposal and reuse.



Wastewater Treatment Systems

Objectives

After studying this unit, you should be able to

- describe the various conventional and advanced technologies in current use,
- explain how they are applied for the effective treatment of municipal wastewater,
- discuss the type of aerobic and anaerobic biological processes and their use in wastewater treatment, and

- conceptualise the biological processes involved in activated sludge process, trickling filter, stabilization pond, rotating biological contactor and aerobic and anaerobic sludge digestion.

7.2 SCREENING

The screening of wastewater, one of the oldest treatment methods, removes gross pollutants from the waste stream to protect downstream equipment from damage, avoid interference with plant operations and prevent objectionable floating material from entering the primary settling tanks. Screening devices may consist of parallel bars, rods or wires, grating, wire mesh, or perforated plates, to intercept large floating or suspended material. The openings may be of any shape, but are generally circular or rectangular. The material retained from the manual or mechanical cleaning of bar racks and screens is referred to as “screenings”, and is either disposed of by burial or incineration, or returned into the waste flow after grinding. The principal types of screening devices are listed in Table 7.1 (also see Figures 7.1 and 7.2).

Table 7.1 : Screen Types

Screen Category	Size of Openings (mm)	Application	Type of Screens
Coarse screens	≥ 6	Remove large solids, rags, and debris.	Manually cleaned bar screens/trash racks Mechanically cleaned bar screens/trash racks Chain or cable driven with front or back cleaning Reciprocating rake screens Catenary screens Continuous self-cleaning screens
Fine screens	1.5-6	Reduce suspended solids to primary treatment levels	Rotary-drum screens Rotary-drum screens with outward or inward flow Rotary-vertical-disk screens Inclined revolving disc screens Traveling water screens Endless band screen Vibrating screens
Very fine screens	0.2-1.5	Reduce suspended solids to primary treatment levels	
Microscreens	0.001-0.3	Upgrade secondary effluent to tertiary standards	

The coarse screen category includes manually or mechanically cleaned bar screens and trash racks. Bar screens consist of vertical or inclined steel bars distributed equally across a channel through which wastewater flows. They are used ahead of mechanical equipment including raw sewage pumps, grit chambers, and primary sedimentation tanks. Trash racks, for their part, are constructed of parallel rectangular or round steel bars with clear openings. Regular bar screens or comminutors usually follows them. Comminutors or macerators is a device that traps the material between their teeth and a fixed comb. Criteria used in the design of coarse screens include bar size, spacing, and angle from the vertical, as well as channel width and wastewater approach velocity. Fine screens consist of various types of screen media, including slotted perforated plates, wire mesh, woven wire cloth and wedge-shaped wire. Due to their tiny openings, fine screens must be cleaned continuously by means of brushes, scrapers, or jets of water, steam, or air forced through the reverse side of the openings. The efficiency of a fine screen depends on the fineness of the openings as well as the sewage flow velocity through those openings.

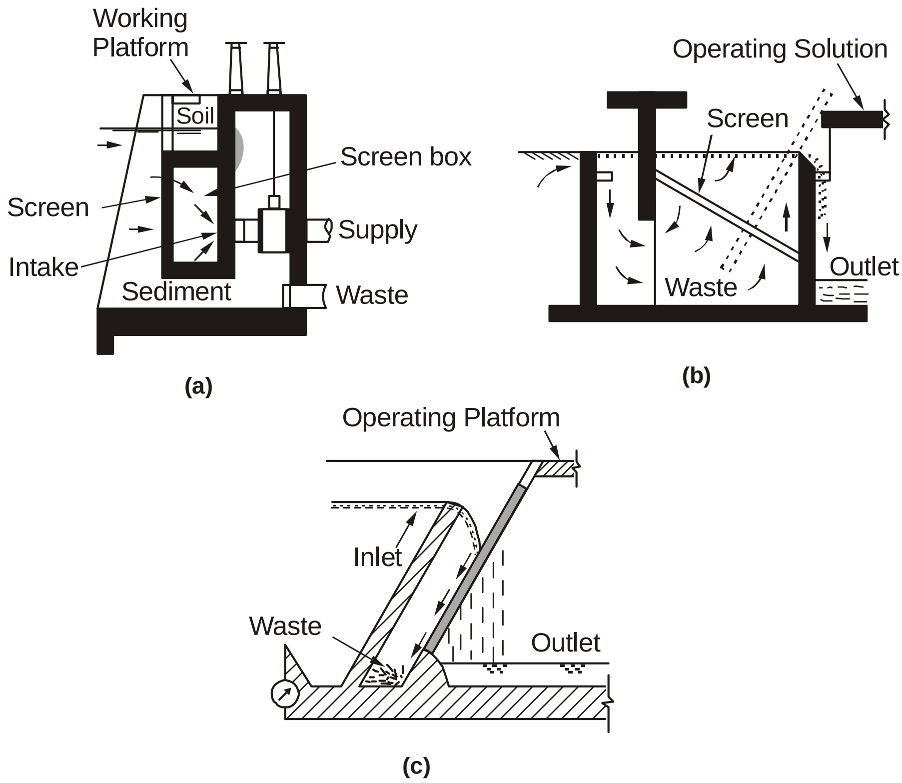


Figure 7.1: Manually Cleaning Fixed Bar Screens : (a) Vertical Rack Cleaned by Hand Operated Long-tined Rake; (b) Inclined Screen with Upward Flow (Screen can be tilted for cleaning); (c) Self-flushing Inclined Screen

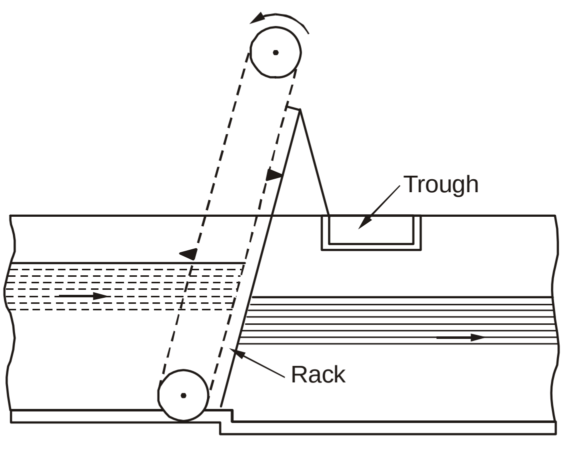


Figure 7.2 : Mechanically Cleaned Bar Screens

7.3 GRIT REMOVAL

Wastewater usually contains a relatively large amount of inorganic solids such as sand, cinders and gravel, which are collectively called grit. The amount present in a particular wastewater depends primarily on whether the collecting sewer system is of the sanitary or combined type. Grit will damage pumps by abrasion and cause serious operation difficulties in sedimentation tanks and sludge digesters by accumulation around and plugging of outlets and pump suctions. Consequently, it is common practice to remove this material by grit chambers.

Grit chambers are usually located ahead of pumps or comminuting devices, and if mechanically cleaned, should be preceded by coarse bar rack screens. Grit chambers are generally designed as long channels. In these channels, the velocity is reduced sufficiently to deposit heavy inorganic solids but to retain organic material in suspension. Channel type chambers should be designed to provide controlled velocities as close as possible to 0.3 meter per second. Velocities substantially smaller than 0.3 meter per second cause excessive organic materials to settle out with the grit.

The detention period is usually between 20 seconds to 1.0 minute. This is attained by providing several chambers to accommodate variation in flow or by proportional weirs at the end of the chamber or other flow control devices, which permit regulation of flow velocity.

One development is the injection of air above the floor of a tank type unit. The rolling action of the air keeps the lighter organic matter in suspension and allows the grit relatively free from organic matter to be deposited in the quiescent zone beneath the zone of air diffusion. Excessive quantities of air can cause the roll velocity to be too high resulting in poor grit removal. Insufficient quantities of air result in low roll velocities and excessive organic matter will settle with the grit. These grit chambers are usually called aerated grit chambers (Figure 7.3).

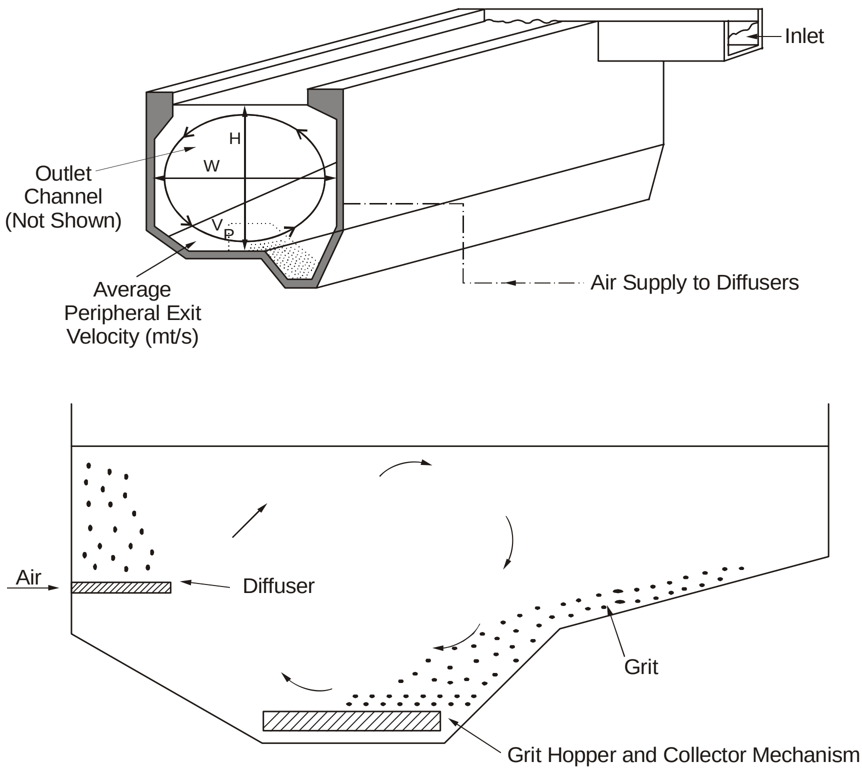


Figure 7.3 : Aerated Grit Chambers

Grit chambers are designed to be cleaned manually or by mechanically operated devices. If cleaned manually, storage space for the deposited grit is usually provided. Grit chambers for plants treating wastes from combined sewers should have at least two hand-cleaned units or a mechanically cleaned unit with by-pass. Mechanically cleaned grit chambers are recommended. Single, hand-cleaned chambers with by-pass are acceptable for small wastewater treatment plants serving sanitary sewer systems. Chambers other than channel type are acceptable, if provided with adequate and flexible controls for agitation and/or air supply devices and with grit removal equipment. There are a number of mechanical cleaning units available which remove grit by scrapers or buckets while the grit chamber is in normal operation. These require much less grit storage space than manually operated units.

Grit always contains some organic matter, which decomposes and creates odours. To facilitate economical disposal of grit without causing nuisance, the organic matter is sometimes washed from the grit and returned to the wastewater. Special equipment is available to wash grit. Mechanical cleaning equipment, generally provides for washing grit with wastewater, as it is removed from the chamber.

Manually cleaned grit chambers for combined wastewater should be cleaned after every large storm. Under ordinary conditions, these grit chambers should be cleaned when the deposited grit has filled 50 to 60 percent of the grit storage space. This should be checked at least every ten days during dry weather. When mechanically cleaned grit chambers are used, they must be cleaned at regular intervals to prevent undue load on the cleaning mechanism. Recommendations of the manufacturer should be rigidly observed. This plus experience, will determine the cleaning schedule. A grit in which marked odours develop indicates that excessive organic matter is being removed in the grit chamber. Alternately, if sludge from a settling tank is excessively high in grit, or if there is excessive wear in pumps, comminutors, sludge collectors or other mechanical equipment, the reason is likely to be inefficient functioning of the grit removing process.

7.4 COMMINUTION

Comminutors are used to pulverize large floating material in the waste flow. They are installed where the handling of screenings would be impractical, generally between the grit chamber and the primary settling tanks. Their use reduces odours, flies and unsightliness. A comminutor may have either rotating or oscillating cutters. Rotating-cutter comminutors either engage a separate stationary screen alongside the cutters, or a combined screen and cutter rotating together. A different type of comminutor, known as a barminutor, involves a combination of a bar screen and rotating cutters.

7.5 FLOW EQUALIZATION

Flow equalization is a technique used to improve the effectiveness of secondary and advanced wastewater treatment processes by levelling out operation parameters such as flow, pollutant levels and temperature over a period of time. Variations are damped until a near-constant flow rate is achieved, minimizing the downstream effects of these parameters. Flow equalization may be applied at a number of locations within a wastewater treatment plant, e.g. near the head end of the treatment works, prior to discharge into a water body, and prior to advanced waste treatment operations.

7.6 OIL AND GREASE REMOVAL

Main sources of oil and grease include kitchens, restaurants, slaughterhouses and garages. Their removal from wastewater is necessary because of the following :

(a) They protect tank walls of subsequent sewage treatment plant facilities from grease deposits.

(b) They protect the biological processes, especially air diffusers from grease deposits.

(c) The oil and grease adversely affect bacteria and protozoa life, which is essential in bio-treatment.

(d) Oil and grease are difficult to digest; hence the cost of digestion is increased.

Oil and grease are generally lighter than water; thereby they float (i.e., rise to surface). Oil and grease removal can be achieved in skimming tanks (Figure 7.4). In the aeration zone, air is injected into the lower level. Settling zone serves as the area to facilitate rising of oil and grease to the surface. Retention time is kept between 10-15 min. Extraction of oil and grease is achieved by either through manual extraction or mechanical skimming of surface or through overflowing.

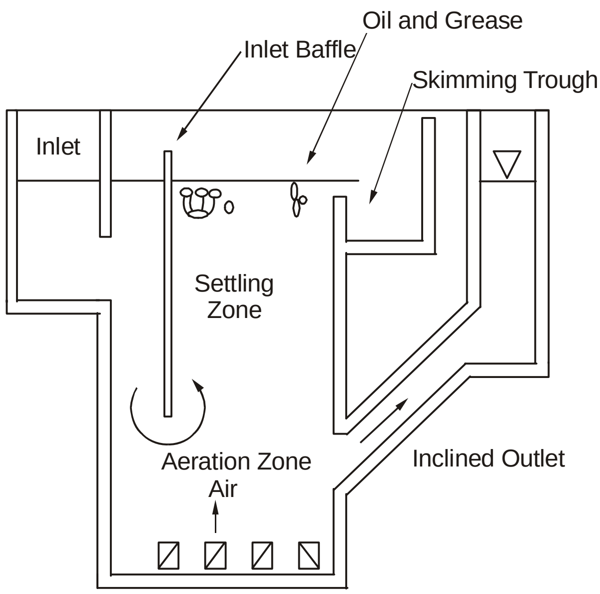


Figure 7.4 : Oil and Grease Removal

SAQ 1

With the help of sketches, describe the principles involved in the design and construction of following

(i) Grit Chamber.

(ii) Screens.

(iii) Skimming Tank.

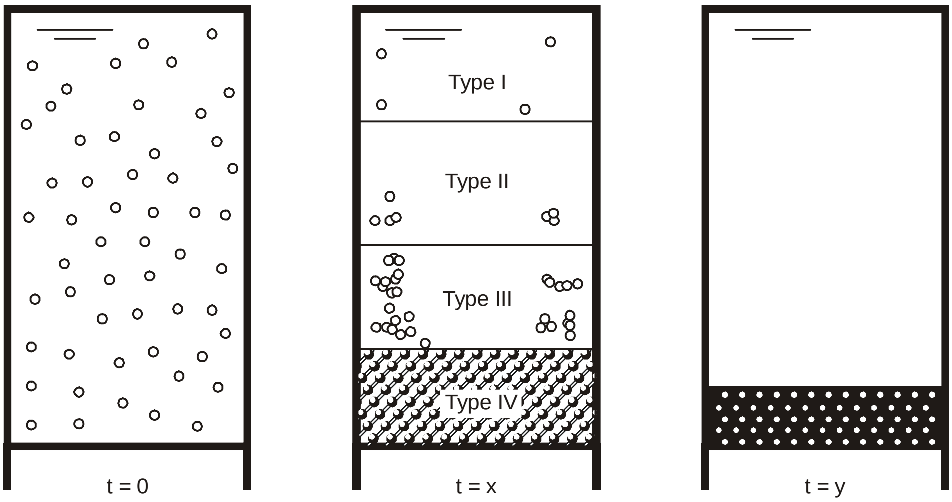
7.7 SEDIMENTATION

Sedimentation, a fundamental and widely used unit operation in wastewater treatment, involves the gravitational settling of heavy particles suspended in a mixture. This process is used for the removal of grit, particulate matter in the primary settling basin, biological floc in the activated sludge settling basin, and chemical flow when the chemical coagulation process is used.

Four types of settling occur, depending on particle concentration: discrete, flocculent, hindered and compression (Figure 7.5). It is common for more than one type of settling to occur during a sedimentation operation.

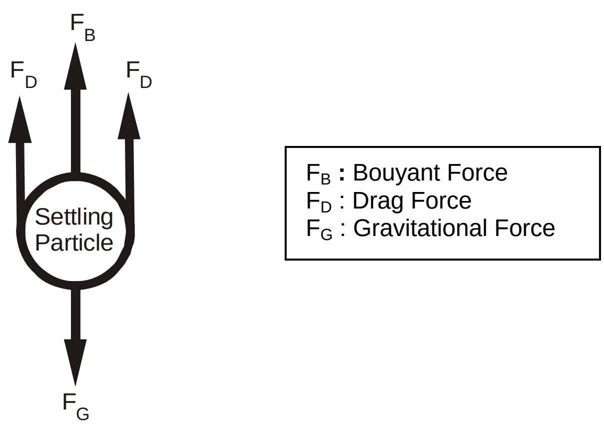
Types of Sedimentation

Type I	:	Discrete particles – no particle interaction.
Type II	:	Flocculating Free Particles – large floc particles "sweep" smaller particles (faster than Type I).
Type III	:	Hindered – limited by fluid flow through particle groups.
Type IV	:	Compression – particles physically interact, water must be squeezed out to compress particle group.



0 < *t* < *y*

(a) Sedimentation of Particles



(b) Forces Acting on a Discrete Settling Particle

Figure 7.5 : Sedimentation of Particles and Forces on a Discrete Settling Particle

The rate of change in the momentum of a settling particle can be written as

$$m_p \frac{dv_s}{dt} = F_G - F_B - F_D$$

where, m_p = Mass of particle (kg),

v_s = Particle settling velocity (m/s),

F_G = Gravitational force (N),

F_B = Buoyant force (N), and

F_D = Drag force (N).

For an ideal system, the terminal settling velocity is attained quickly and the acceleration term can be neglected. Thus, the force balance on a settling particle can be written as follows:

$$m_p \frac{dv_s}{dt} = 0 = F_G - F_B - F_D$$

or $$F_D = F_G - F_B$$

Size Determination for Sedimentation Basin

Important aspects in the determination of size of sedimentation basin are the following :

- Surface loading ($m^3/m^2/h$)
- Detention time (h)
- Weir loading rate ($m^3/m/h$)

Sedimentation rate of SS depends on the size of sedimentation particles.

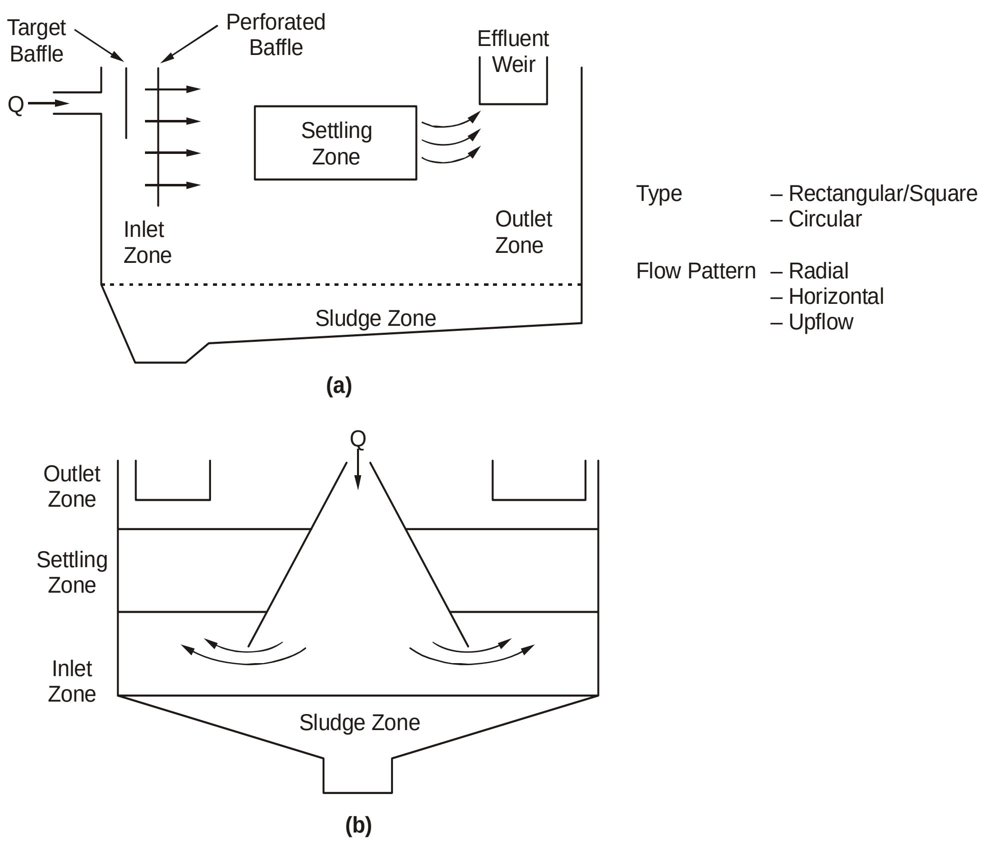


Figure 7.6 : Zones of Sedimentation; (a) Horizontal Flow Clarifier; and (b) Up Flow Clarifier

Inlet Zone

It evenly distributes the flow and suspended solids across the cross-section of the settling zones. It covers approximately 25% of the tank length.

Settling Zone

Where the actual settling of particles takes place.

Sludge Collection Zone of Sludge

Configuration and depth of the sludge zone depends on the method of cleaning and quantity of sludge deposited. Well flocculated solids, 75% settle in the 1/5th of the tank length.

Outlet Zone

Removal of settled water without carrying away any of the flocs. Should be designed to avoid scouring by having either weirs or trough.

Determination of Settling Velocity

Figure 7.7 shows settling paths of discrete particles in a idealised horizontal flow tank.

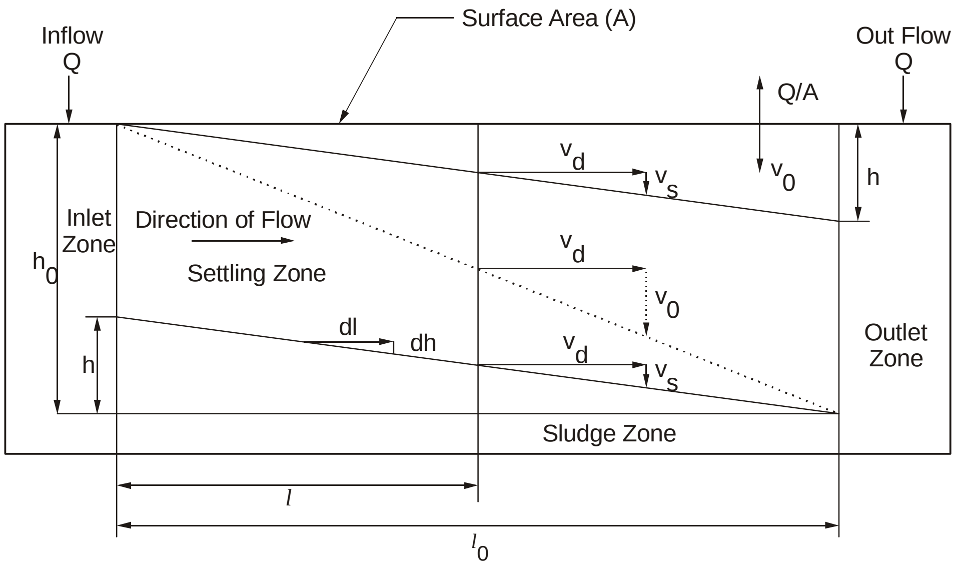


Figure 7.7 : Settling Paths of Discrete Particles in a Horizontal Flow Tank (Idealised)

In Figure 7.7, v_o is the velocity of the particle falling through the full depth h_0 of the settling zone in the detention time t_0. In Figure 7.7 above v_d is the displacement velocity and v_s is the settling velocity.

Therefore, $$v_0 = \frac{h_0}{t_0}$$

$$t_0 = \frac{V}{Q} = \frac{l \times w \times h_0}{Q}$$

where, V = Volume of the settling tank, and

w = Width of the channel.

Therefore, surface loading or overflow velocity can be further written as

$$v_0 = \frac{Q}{l \times w} = \frac{Q}{A_s}$$

where, A_s = Surface area.

Therefore, removal of particles from the tank is independent of the depth of the tank. All particles with $v_s \geq v_0$ are removed by way of settling in the tank. Thus, the horizontal velocity component or displacement velocity v_d should not be very high else the particles will not settle and get washed away.

For design calculations,

$$v_o = 0.8\, v_s$$

Particles of $v_s < v_0$ can be removed from horizontal flow basins if they are within vertical striking distance of $\frac{v_s}{v_d} \times l_0$ from the sludge zone.

Settling of dilute suspensions which have little or no tendency to flocculate; Type I Sedimentation (Discrete Particle Settling) is assumed. Considering spherical particles, the terminal velocity is given as

$$v_c = \frac{g\,(\rho_s - \rho_L)}{18\,\mu}\, d^2$$

where, v_c = Terminal velocity,

ρ_s = Density of the particle,

ρ_L = Density of the liquid,

g = Acceleration due to gravity,

d = Diameter of particle, and

μ = Dynamic viscosity.

In the design of sedimentation basins, select a particle with terminal velocity v_c and design the basin so that all particles that have settling velocity equal to or greater than v_c will be removed.

Typical Overflow Rates in Wastewater Applications

Wastewater Treatment

Primary settling = 22-60 m/d;

Activated Sludge = 10-32 m/d;

Ideal Sedimentation Design Assumptions

(a) Homogeneous inlet zone (same particle size distribution at all depths).

(b) Discrete particle (Type I) settling.

(c) Uniform horizontal flow in sedimentation zone.

(d) Outlet zone to transfer uniform flow to discharge flow.

(e) Particles are not re-suspended from sludge zone.

(f) All particles with settling velocity greater than the critical velocity (v_{sc}) settle to the sludge zone.

Non-ideal Sedimentation

Variations from Ideal Sedimentation is caused by :

(a) Wind currents

(b) Temperature gradients

(c) Density flows

(d) Type II, III and IV settling

Types of Clarifiers

Sedimentation takes place in a settling tank, also referred to as a clarifier. There are three main designs, namely, horizontal flow, solids contact and inclined surface. In designing a sedimentation basin, it is important to bear in mind that the system must produce both a clarified effluent and a concentrated sludge.

Horizontal Flow

Horizontal-flow clarifiers may be rectangular, square or circular in shape. The flow in rectangular basins is rectilinear and parallel to the long axis of the basin, whereas in centre-feed circular basins, the water flows radially from the centre towards the outer edges. Both types of basins are designed to keep the velocity and flow distributions as uniform as possible in order to prevent currents and eddies from forming, and thereby keep the suspended material from settling. Basins are usually made of steel or reinforced concrete. The bottom surface slopes slightly to facilitate sludge removal. In rectangular tanks, the slope is towards the inlet end, while in circular and square tanks, the bottom is conical and slopes towards the centre of the basin.

Solid Contact Clarifiers

Solid contact clarifiers bring incoming solids into contact with a suspended layer of sludge near the bottom that acts as a blanket. The incoming solids agglomerate and remain enmeshed within the sludge blanket, whereby the liquid is able to rise upwards while the solids are retained below.

Inclined Surface Basins

Inclined surface basins, also known as high-rate settlers, use inclined trays to divide the depth into shallower sections, thus reducing particle settling times. They also provide a larger surface area, so that a smaller-sized clarifier can be used. Many overloaded horizontal flow clarifiers have been upgraded to inclined surface basins. Here, the flow is laminar, and there is no wind effect.

SAQ 2

(a) Differentiate between discrete particle settling, flocculent settling, hindered settling and compression settling.

(b) Discuss different types of clarifier.

7.8 FLOTATION

Flotation is a unit operation used to remove solid or liquid particles from a liquid phase by introducing a fine gas, usually air bubbles. The gas bubbles either adhere to the liquid or are trapped in the particle structure of the suspended solids, raising the buoyant force of the combined particle and gas bubbles.

Particles that have a higher density than the liquid can thus be made to rise. In wastewater treatment, flotation is used mainly to remove suspended matter and to concentrate biological sludge. The main advantage of flotation over sedimentation is that very small or light particles can be removed more completely and in a shorter time. Once the particles have been floated to the surface, they can be skimmed out. Flotation, as currently practised in municipal wastewater treatment, uses air exclusively as the floating agent. Furthermore, various chemical additives can be introduced to enhance the removal process. Various flotation methods are described in Table 7.2, while a typical flotation unit is illustrated in Figure 7.8.

Table 7.2 : Flotation Methods

Process	Description
Dissolved-air flotation	The injection of air while wastewater is under the pressure of several atmospheres. After a short holding time, the pressure is restored to atmospheric level, allowing the air to be released as minute bubbles.
Air flotation	The introduction of gas into the liquid phase directly by means of a revolving impeller or through diffusers, at atmospheric pressure.
Vacuum flotation	The saturation of wastewater with air either directly in an aeration tank or by permitting air to enter on the suction side of a wastewater pump. A partial vacuum is applied, causing the dissolved air to come out of solution as minute bubbles which rise with the attached solids to the surface, where they form a scum blanket. The scum is removed by a skimming mechanism while the settled grit is raked to a central sump for removal.
Chemical additives	Chemicals further the flotation process by creating a surface that can easily adsorb or entrap air bubbles. Inorganic chemicals (aluminum and ferric salts and activated silica) and various organic polymers can be used for this purpose.

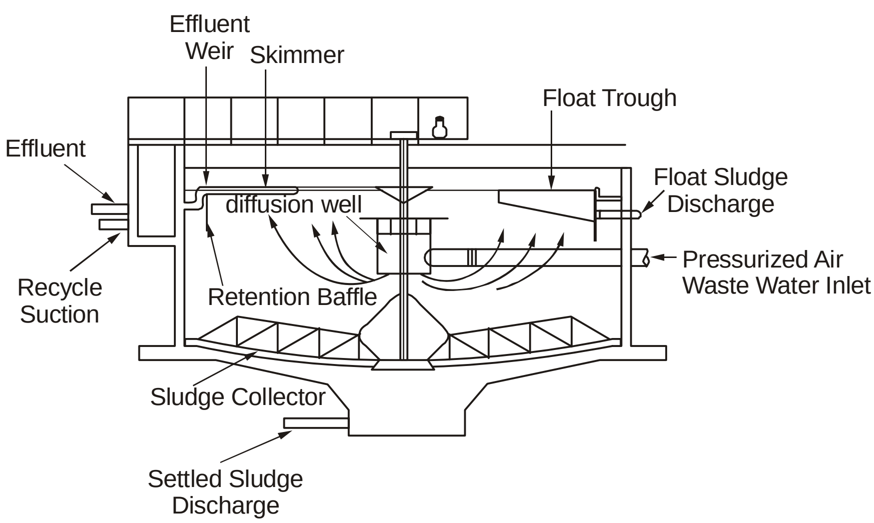
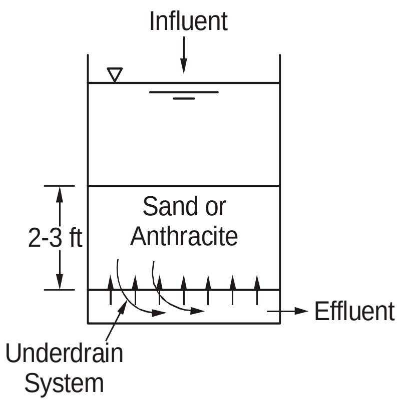


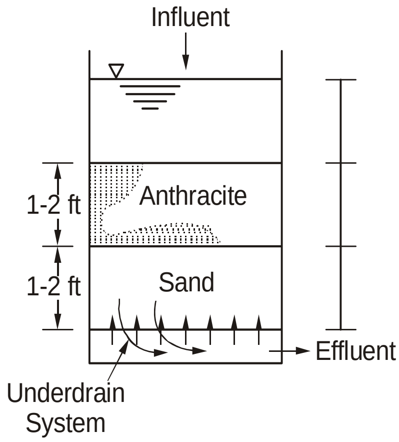
Figure 7.8 : Typical Flotation Unit

7.9 GRANULAR MEDIUM FILTRATION

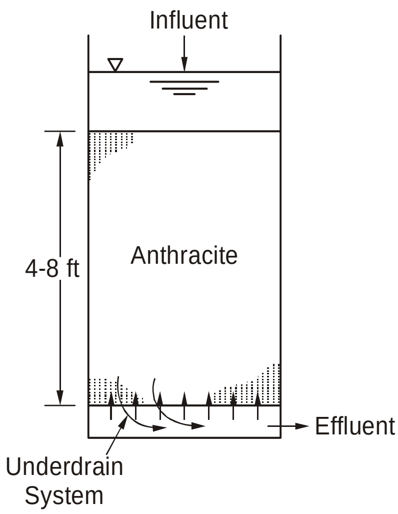
The filtration of effluents from wastewater treatment processes is a relatively recent practice, but has come to be widely used for the supplemental removal of suspended solids from wastewater effluents of biological and chemical treatment processes, in addition to the removal of chemically precipitated phosphorus. The complete filtration operation comprises two phases: filtration and cleaning or backwashing. The wastewater to be filtered is passed through a filter bed consisting of granular material (sand, anthracite and/or garnet), with or without added chemicals. Within the filter bed, suspended solids contained in the wastewater are removed by means of a complex process involving one or more removal mechanisms such as straining, interception, impaction, sedimentation, flocculation and adsorption. The phenomena that occur during the filtration phase are basically the same for all types of filters used for wastewater filtration. The cleaning/backwashing phase differs, depending on whether the filter operation is continuous or semicontinuous. In semi-continuous filtration, the filtering and cleaning operations occur sequentially, whereas in continuous filtration the filtering and cleaning operations occur simultaneously. The operational characteristics of the various forms of granular medium filters commonly used for wastewater filtration are illustrated in Figure 7.9.



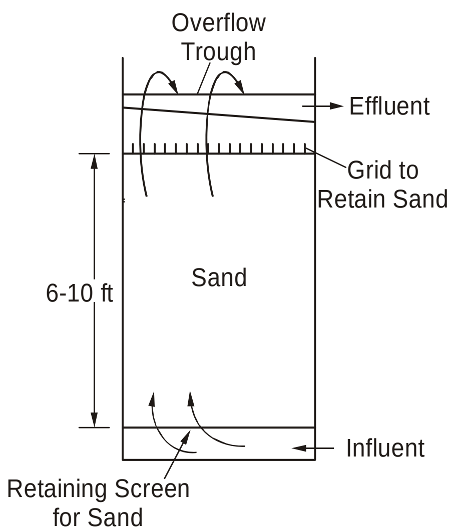
(a) Conventional Mono-medium Downflow



(b) Conventional Dual-medium Downflow



(c) Conventional Mono-medium Deep-bed Downflow



(d) Conventional Mono-medium Deep-bed Downflow

Figure 7.9 : Granular Medium Filters

7.10 CHEMICAL UNIT PROCESSES

Chemical processes used in wastewater treatment are designed to bring about some form of change by means of chemical reactions. They are always used in conjunction with physical unit operations and biological processes. In general, chemical unit processes have an inherent disadvantage compared to physical operations in that they are additive processes. That is to say, there is usually a net increase in the dissolved constituents of the wastewater. This can be a significant factor if the wastewater is to be reused. This section discusses the main chemical unit processes, including chemical precipitation, adsorption, disinfection, dechlorination and other applications.

7.10.1 Chemical Precipitation

Chemical coagulation of raw wastewater before sedimentation promotes the flocculation of finely divided solids into more readily settleable flocs, thereby enhancing the efficiency of suspended solid, BOD and phosphorus removal as compared to plain sedimentation without coagulation (Table 7.3). The degree of clarification obtained depends on the quantity of chemicals used and the care with which the process is controlled.

Table 7.3 : Removal Efficiency of Plain Sedimentation vs Chemical Precipitation

Parameter	Percentage Removal	
	Plain Sedimentation	Chemical Precipitation
Total suspended solids (TSS)	40-90	60-90
BOD	25-40	40-70
COD		30-60
Phosphorus	5-10	70-90
Bacteria loadings	50-60	80-90

Coagulant selection for enhanced sedimentation is based on performance, reliability and cost. Performance evaluation uses jar tests of the actual wastewater to determine dosages and effectiveness. Chemical coagulants that are commonly used in waste-water treatment include alum ($Al_2(SO_4)_3.18.3\ H_2O$), ferric chloride ($FeCl_3.6H_2O$), ferric sulphate ($Fe_2(SO_4)_3$), ferrous sulphate ($FeSO_4.7H_2O$) and lime ($Ca(OH)_2$). Organic polyelectrolytes are sometimes used as flocculation aids. Suspended solids removal through chemical treatment involves a series of three unit operations: rapid mixing, flocculation and settling. First, the chemical is added and completely dispersed throughout the wastewater by rapid mixing for 20-30 seconds in a basin with a turbine mixer. Coagulated particles are then brought together via flocculation by mechanically inducing velocity gradients within the liquid. Flocculation takes 15 to 30 minutes in a basin containing turbine or paddle-type mixers. The final step is the clarification by gravity. A once-through chemical treatment system is illustrated in Figure 7.10.

The advantages of coagulation include greater removal efficiency, the feasibility of using higher overflow rates and more consistent performance. On the other hand, coagulation results in a larger mass of primary sludge that is often more difficult to thicken and dewater. It also entails higher operational costs and demands greater attention on the part of the operator.

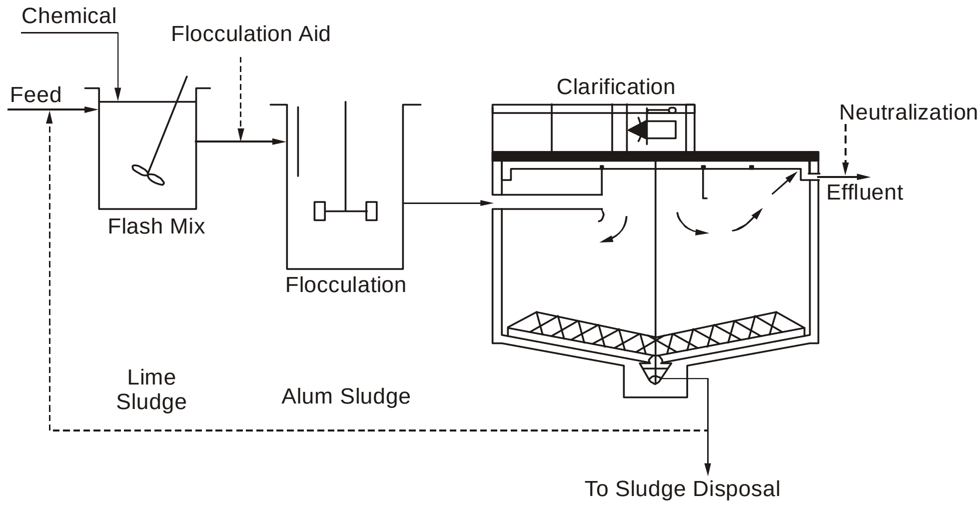


Figure 7.10 : A Once-Through Chemical Treatment System

7.10.2 Adsorption with Activated Carbon

Adsorption is the process of collecting soluble substances within a solution on a suitable interface. In wastewater treatment, adsorption with activated carbon – a solid interface – usually follows normal biological treatment, and is aimed at removing a portion of the remaining dissolved organic matter. Particulate matter present in the water may also be removed. Activated carbon is produced by heating char to a high temperature and then activating it by exposure to an oxidizing gas at high temperature. The gas develops a porous structure in the char and thus creates a large internal surface area. The activated char can then be separated into various sizes with different adsorption capacities. The two most common types of activated carbon are granular activated carbon (GAC), which has a diameter greater than 0.1 mm, and powdered activated carbon (PAC), which has a diameter of less than 200 mesh. A fixed-bed column is often used to bring the waste-water into contact with GAC. The water is applied to the top of the column and withdrawn from the bottom, while the carbon is held in place.

Backwashing and surface washing are applied to limit headloss build-up. Expanded-bed and moving-bed carbon contactors have been developed to overcome the problem of headloss build-up. In the expanded-bed system, the influent is introduced at the bottom of the column and is allowed to expand. In the moving-bed system, spent carbon is continuously replaced with fresh carbon. Spent granular carbon can be regenerated by removal of the adsorbed organic matter from its surface through oxidation in a furnace. The capacity of the regenerated carbon is slightly less than that of the virgin carbon. Wastewater treatment using PAC involves the addition of the powder directly to the biological treatment effluent or the physiochemical treatment process, as the case may be. PAC is usually added to wastewater in a contacting basin for a certain length of time. It is then allowed to settle to the bottom of the tank and removed. Removal of the powdered carbon may be facilitated by the addition of polyelectrolyte coagulants or filtration through granular-medium filters. A major problem with the use of powdered activated carbon is that the methodology for its regeneration is not well defined.

7.10.3 Disinfection

Disinfection refers to the selective destruction of disease-causing micro-organisms. This process is of importance in wastewater treatment owing to the nature of wastewater, which harbours a number of human centeric organisms that are associated with various waterborne diseases. Commonly used means of disinfection include the following :

(a) Physical agents such as heat and light.

(b) Mechanical means such as screening, sedimentation, filtration, and so on.

(c) Radiation, mainly gamma rays.

(d) Chemical agents including chlorine and its compounds, bromine, iodine, ozone, phenol and phenolic compounds, alcohols, heavy metals, dyes, soaps and synthetic detergents, quaternary ammonium compounds, hydrogen peroxide and various alkalis and acids.

The most common chemical disinfectants are the oxidizing chemicals, and of these, chlorine is the most widely used.

Disinfectants act through one or more of a number of mechanisms, including damaging the cell wall, altering cell permeability, the colloidal nature of the protoplasm and inhibiting enzyme activity. In applying disinfecting agents, several factors need to be considered, i.e. contact time, concentration and type of chemical agent, intensity and nature of physical agent, temperature, number of organisms, and nature of suspending liquid.

Dechlorination

Dechlorination is the removal of free and total combined chlorine residue from chlorinated wastewater effluent before its reuse or discharge to receiving waters. Chlorine compounds react with many organic compounds in the effluent to produce undesired toxic compounds that cause long-term adverse impacts on the water environment and potentially toxic effects on aquatic microorganisms. Dechlorination may be brought about by the use of activated carbon, or by the addition of a reducing agent such as sulphur dioxide (SO_2), sodium sulphite (Na_2SO_3) or sodium metabisulphite ($Na_2S_2O_5$). It is important to note that dechlorination will not remove toxic by-products that have already been produced.

7.10.4 Other Chemical Applications

In addition to the chemical processes described above, various other applications are occasionally encountered in wastewater treatment and disposal. Table 7.4 lists the most common applications and the chemicals used.

Table 7.4 : Other Chemical Applications in Wastewater Treatment and Disposal

Application	Chemical Used	Remarks
Treatment		
➢ pH control	KOH, NaOH, Ca $(OH)_2$	
➢ Filter-fly control	Cl_2	Residual at filter nozzles, used during fly season
➢ Sludge-bulking control	Cl_2, H_2O_2, O_3	Temporary control measure
➢ Odour control	Cl_2, H_2O_2, O_3	
➢ Oxidation of refractory organic compounds	O_3	
Disposal		
➢ Bacterial reduction	Cl_2, H_2O_2, O_3	Plant effluent, overflows,

		and stormwater
➢ Odour control	Cl_2, H_2O_2, O_3	

7.11 BIOLOGICAL TREATMENT UNITS AND PROCESSES

Biological unit processes are used to convert the finely divided and dissolved organic matter in wastewater into flocculent settleable organic and inorganic solids. In these processes, micro-organisms, particularly bacteria, convert the colloidal and dissolved carbonaceous organic matter into various gases and into cell tissue, which is then removed in sedimentation tanks. Biological processes are usually used in conjunction with physical and chemical processes, with the main objective of reducing the organic content (measured as BOD, TOC or COD) and nutrient content (notably nitrogen and phosphorus) of wastewater.

Biological processes used for wastewater treatment may be classified under five major headings :

(a) Aerobic processes.

(b) Anoxic processes.

(c) Anaerobic processes.

(d) Combined processes.

(e) Pond processes.

These processes are further subdivided, depending on whether the treatment takes place in a suspended growth system, an attached-growth system or a combination of both. This unit will be concerned with the most commonly used biological processes, including trickling filters, the activated sludge process, aerated lagoons, rotating biological contactors and stabilization ponds.

7.12 THE ROLE OF MICRO-ORGANISMS IN BIOLOGICAL PROCESSES

Micro-organisms, such as bacteria, play an important role in the natural cycling of materials and particularly in the decomposition of organic wastes. The role of micro-organisms is elaborated further here because they are also important in the treatment of wastewater. What is waste for humans and higher vertebrates becomes a useful food substrate for the micro-organisms. In both natural and engineered treatment systems, micro-organisms such as bacteria, fungi, protozoa, and crustaceans play an essential role in the conversion of organic waste to more stable less polluting substances. They form what is termed a ‘food chain’. For example, inorganic and organic substances in wastes are consumed by bacteria, fungi and algae. These are in turn consumed by protozoa and nematodes (some fungi however trap nematodes) and the latter by rotifers.

Micro-organisms are always present in the environment and given the right conditions of food availability, temperature and other environmental factors, they grow and multiply. Micro-organisms require cellular building blocks, such as C (carbon), H (hydrogen), O (oxygen), N (nitrogen), P (phosphorus) and minerals for growth. These can be obtained through consuming organic substances containing these elements, or from inorganic materials, such as carbon dioxide, water, nitrate and phosphate. Micro-organisms also require energy. They obtain this through respiration. In this process, organic carbon is oxidised to release its energy. Oxygen or other hydrogen acceptors is needed for the respiration process. Algae and photosynthetic bacteria can also utilise energy from sunlight, while certain types of bacteria can utilise energy from chemical reactions not involving respiration. The building blocks and energy are used to synthesise more cells for growth and also for reproduction.

In the treatment of wastewater, three types of overall processes are distinguished to represent the conversion of organic wastes by micro-organisms. The classification is based on whether the environment where the process takes place is aerobic, anaerobic or photosynthetic. Under aerobic conditions (in the presence of oxygen), micro-organisms utilise oxygen to oxidise organic substances to obtain energy for maintenance, mobility and the synthesis of cellular material. Under anaerobic conditions (in the absence of oxygen), the micro-organisms utilise nitrates, sulphates and other hydrogen acceptors to obtain energy for the synthesis of cellular material from organic substances. Photosynthetic organisms use carbon dioxide as a carbon source, inorganic nutrients as sources of phosphate and nitrogen and utilise light energy to drive the conversion process.

Micro-organisms also produce waste products, some of which are desirable and some undesirable. Gases such as carbon dioxide and nitrogen are desirable, since they can be easily separated and do not produce pollution. Gases such as hydrogen sulphide and mercaptans, although easily separated require treatment for odour. Micro-organisms' cellular materials are organic in nature and can also cause pollution. It would be desirable if the cellular materials have undergone self oxidation (endogeneous respiration utilising own body cells) to produce non-biodegradable materials that are relatively stable. Self-oxidation is achieved when there is no substrate/food available.

The microbiological conversion reactions of organic waste into cellular material can be empirically represented as shown in Figure 7.11.

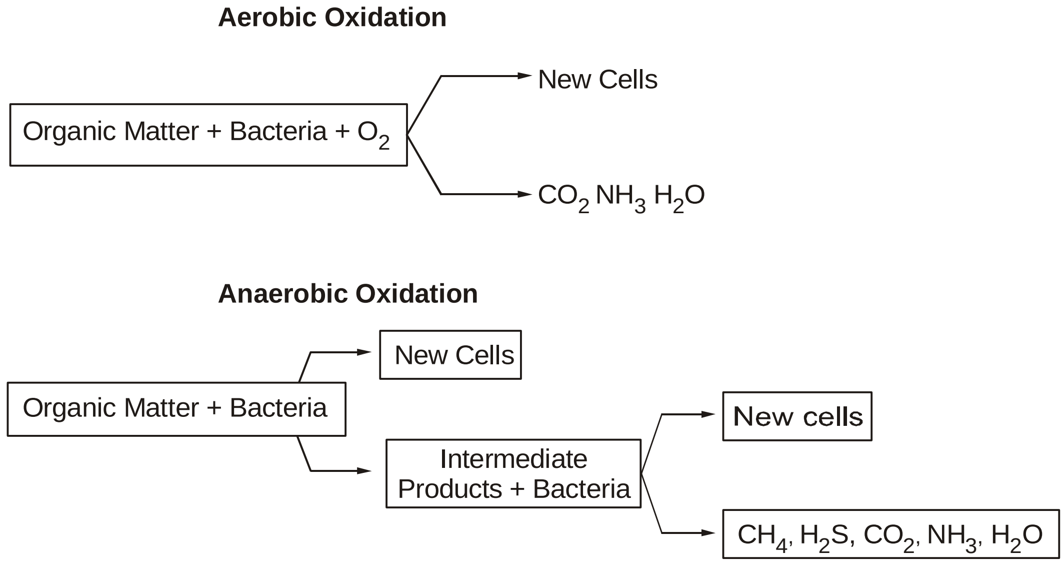


Figure 7.11 : Microbiological Conversion Reactions

Conversion under Aerobic Conditions

Under aerobic conditions ammonia is further oxidised to nitrate. Phosphorus and sulphur contained in the organic substances are oxidised to phosphate and sulphate. These can be further utilised by the micro-organisms for synthesis.

Conversion under Anaerobic Conditions

Methane (CH_4) is a useful gaseous by-product of anaerobic conversion, because it can be combusted to produce heat/energy. On the other hand if it is released to the atmosphere without being combusted, it contributes to the greenhouse gas effect.

Conversion under Photosynthetic Conditions

$$\text{Sunlight and } CO_2 + rH_2O + tNH_3 \rightarrow C_w\,H_x\,O_y\,N_z + bO_2$$

As shown by the conversion reactions (the utilisation of organic wastes for food by micro-organisms) the product is mainly the cellular material of the micro-organisms, i.e. more organisms are produced. The growth yield is the weight of micro-organisms produced per unit weight of organic substances consumed by the micro-organisms. The growth yield depends on the type of substrate and environmental conditions. The smaller the value of the growth yield the better it is for waste treatment, because less sludge is produced which requires disposal. Its value is usually between 0.2 and 0.5 for aerobic conversion, while the corresponding value for anaerobic conversion is smaller

SAQ 3

Explain the role of micro-organisms in aerobic biological conversion.

7.13 BIOLOGICAL TREATMENT OF WASTEWATER

Biological treatment utilizes microbial action to decompose these high-energy molecules. There are two basic approaches to biological treatment, differing in the manner in which the waste is brought into contact with the micro-organisms. In *suspended growth reactors*, the organisms and waste material are mixed together, while in *fixed film reactors,* the organisms are held in place and the waste stream is passed by.

7.13.1 Activated Sludge Process

The most commonly applied biological treatment system is a suspended growth approach called the *activated sludge* process.

The activated-sludge process is an aerobic, continuous-flow system containing a mass of activated micro-organisms that are capable of stabilizing organic matter. Activated sludge systems are designed to maintain intimate contact between the wastewater, a large population of bacteria and oxygen. The micro-organisms are "activated" for rapid uptake of new substrate, thus the term activated sludge. The process consists of delivering clarified wastewater, after primary settling, into an aeration basin where it is mixed with an active mass of micro-organisms, mainly bacteria and protozoa, which aerobically degrade organic matter into carbon dioxide, water, new cells and other end products. The bacteria involved in activated sludge systems are primarily gram-negative species, including carbon oxidizers, nitrogen oxidizers, floc formers and non-floc formers, and aerobes and facultative anaerobes. The protozoa, for their part, include flagellates, amoebas and ciliates. An aerobic environment is maintained in the basin by means of diffused or mechanical aeration, which also serves to keep the contents of the reactor (or mixed liquor) completely mixed. After a specific retention time, the mixed liquor passes into the secondary clarifier, where the sludge is allowed to settle and a clarified effluent is produced for discharge. The process recycles a portion of the settled sludge back to the aeration basin to maintain the required activated sludge concentration (Figure 7.12). The process also intentionally wastes a portion of the settled sludge to maintain the required solids retention time (SRT) for effective organic removal.

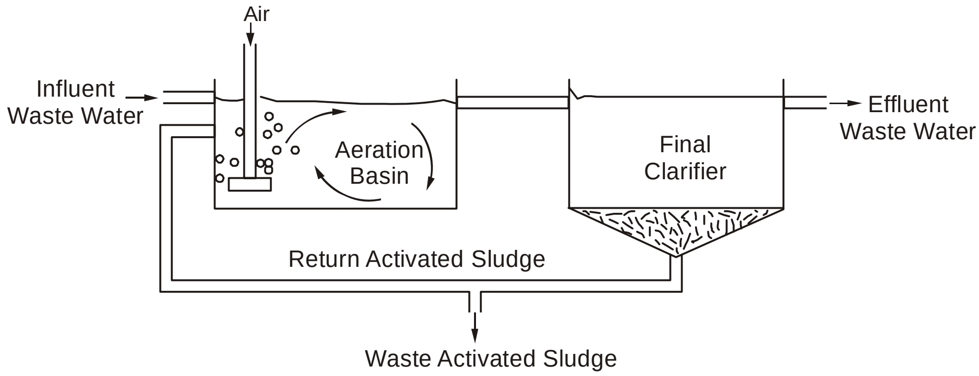


Figure 7.12(a) : Typical Flow Diagram for an Activated-sludge Process : Aeration Tank and Secondary Clarifier

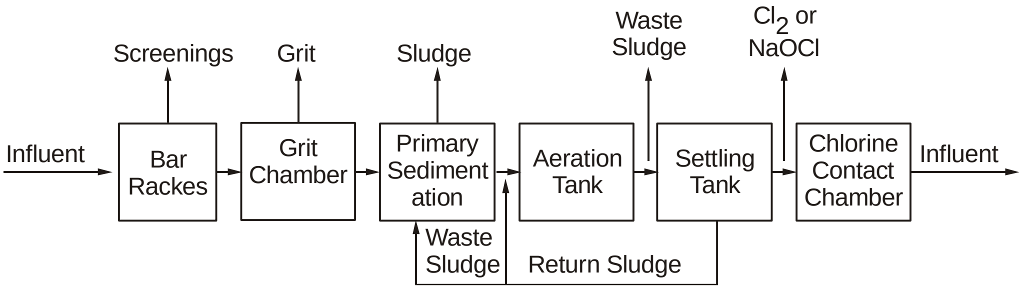


Figure 7.12(b) : Typical Flow Diagram for an Activated-sludge Process : Sequence of Wastewater Treatment Units Including Aeration Tank and Secondary Clarifier

Control of the activated-sludge process is important to maintain a high treatment performance level under a wide range of operating conditions. The principal factors in process control are the following :

(a) Maintenance of dissolved oxygen levels in the aeration tanks.

(b) Regulation of the amount of returning activated sludge.

(c) Control of the waste activated sludge.

Design of Activated Sludge Process

Effluent from the primary clarifier is introduced to an aeration tank and mixed with a mass of micro-organisms comprised bacteria, fungi, rotifers and protozoa. This mixture of liquid, solid waste and micro-organisms is called the mixed liquor suspended solids (MLSS, mg/l). The organisms absorb dissolved organics and break them down into carbon dioxide, water and some stable compounds. Bacteria are primarily responsible for assimilating the organic matter in wastewater, and the rotifers and protozoa are helpful in removing the dispersed bacteria which otherwise would not settle out. The energy derived from the decomposition process is used for cell maintenance and to produce more micro-organisms. Once most of the dissolved organics have been used up, the MLSS is routed to the secondary (or final) clarifier for separation. As with primary settling, two streams are produced : a clarified effluent, which is sent to the next stage of treatment and a liquid sludge comprised largely of micro-organisms. Lying at the bottom of the final clarifier, without a food source, these organisms become nutrient-starved or "activated". A portion of the sludge is then pumped to the head of the tank (return activated sludge) where the process starts all over again. The remainder of the sludge is processed for disposal (waste activated sludge). It is necessary to continuously add waste sludge to balance the gain through microbial growth.

The activated sludge system is a continuous process involving the introduction, uptake and breakdown of BOD and the growth and decay of micro-organisms. An equilibrium is reached where the rate of food introduction and the size of the microbial population are in balance leading to a constant BOD concentration in the effluent. The rate of food introduction (BOD loading) is largely fixed by the sewage inflow rate (Q_o) and BOD (S_o) of the influent. The size of the microbial population is equal to the product of the MLSS concentration in the reactor (X) and the reactor volume (V). Operating experience in waste treatment plants suggests that MLSS concentrations in the reactor should be maintained at levels ranging from 1000-4000 mg/l. Too low concentrations (< 1000 mg/l) lead to poor settling and too high concentrations (> 4000 mg/l) result in solids loss in the clarifier overflow and excessive oxygen requirements. The key process design parameter, used to estimate the required tank volume, is the *food to micro-organism* (*F/M*) *ratio*. Essentially a feeding rate, the F/M ratio is equivalent to the BOD loading rate divided by the mass of MLSS in the reactor :

$$\frac{F}{M} = \frac{Q\ S_0}{(X\ .\ V)}$$

where, S_o = Influent BOD concentration (kg/m^3),

Q = Wastewater Inflow (m^3/d),

X = MLSS concentration (kg/m^3), and

V = Reactor volume (m^3).

Hydraulic retention time (θ) $= \dfrac{V}{Q}$.

Because S_o, Q_o, and X are largely fixed, a particular reactor volume is selected to achieve the desired F/M ratio. It is clear from the equation above that the F/M ratio is really a feeding rate. The lower the F/M ratio, the lower the feeding rate, the hungrier the micro-organisms and the more efficient the removal.

At low F/M ratios, the micro-organisms are maintained in the *death or endogenous growth* phase, i.e. they are starved and, thus, very efficient at BOD removal. Because S_o is relatively constant for domestic wastes and because there are limits on the levels of X which a reactor can support, maintenance of a low F/M ratio requires either a very small flow or a very large tank volume. In either case, this leads to a long hydraulic residence (aeration) time. Activated sludge operated at low F/M ratios is termed *extended aeration.* The cost of operation and maintenance is high for large tank volumes and thus extended aeration is largely limited to systems with small organic loads, e.g. mobile home parks and recreational facilities. At high F/M ratios, the micro-organisms are maintained in the *accelerating or exponential growth* phase.

These organisms are more food-saturated, i.e. there is an excess of substrate, and, thus, BOD removal is less efficient. This approach is termed *high-rate activated sludge*. In this approach, higher MLSS concentrations are employed and, thus, a shorter hydraulic residence time is achieved and smaller aeration tank volumes are required.

Operation of the activated sludge process at mid-range F/M ratios, with micro-organisms in the *declining growth* phase, is termed *conventional activated sludge.* This option offers a balance between removal efficiency and cost of operation. In addition to influencing BOD removal efficiency, the selection of an F/M ratio impacts the settleability of the sludge flocs and, thus, the efficiency of SS removal. In general, as the F/M ratio decreases the settleability of the sludge increases. Starving micro-organisms flocculate and, thus, settle well, while those maintained at high F/M ratios form buoyant filamentous growths, which settle poorly, a condition termed *sludge bulking.*

In order to keep the F/M stable, some MLSS must be continuously wasted to balance micro-organism biomass produced through growth. The design and operation parameter for determining rates of MLSS wastage is the *solids retention time or sludge age* (θ_c, days), defined as the mass of solids present in the reactor over the mass of solids wasted per unit time :

$$\theta_c = \left[\frac{X \times V}{X_w \times Q_w} \right]$$

where Q_w is the waste sludge flow from the reactor (m^3/d). Values for θ_c ranging from 3-15 days result in the production of a stable, high-quality effluent with excellent settling characteristics. Values of X and V are dictated by F/M design considerations. Thus, recommended values for θ_c can be used to calculate the required waste sludge flow.

We can also write,

$$\frac{1}{\theta_c} = \left[\frac{X_w \times Q_w}{X \times V} \right]$$

A rational loading parameter, which has found wide acceptance, is the specific substrate utilization rate, U, per day, which is defined as,

$$U = Q \frac{(S_o - S)}{VX}$$

where, S is the effluent substrate concentration or effluent soluble BOD.

Under steady state operation the mass of waste activated sludge is given by

$$Q_w X_s = Y Q (S_o - S) - k_d \; X V$$

where, Y = Maximum yield coefficient (microbial mass synthesized/mass of substrate utilized),

k_d = Micro-organism decay coefficient,

X_s = MLSS concentration in waste activated sludge from secondary settling tank underflow (g/m^3), and

Q_w = Waste activated sludge rate (m^3/day).

Example Problem : Design of the Aeration Basin Based on Solids Retention Time

You are provided the following information about a municipal wastewater treatment plant. This plant will use the traditional activated sludge process. Population = 150,000 people, flow rate of 33.75×10^6 l/day (equals 225 l/person/day) and influent BOD5 concentration of 444 mg/l (note this is high strength wastewater). Assume that the regulatory agency enforces an effluent standard of BOD5 = 20 mg/l and suspended solids standard of 20 mg/l in the treated wastewater. A wastewater sample is collected from the biological reactor and is found to contain a suspended solids concentration of 4,300 mg/l. The suspended solids concentration in the secondary sludge is 15,000 mg/l and the concentration in the secondary sludge is 5,000 mg/l. The concentration of suspended solids in the plant influent is 200 mg/l and that which leaves the primary clarifier is 100 mg/l. The microorganisms in the activated sludge process can convert 100 grams of BOD5 into 55 grams of biomass. They have a maximum growth rate of 0.1/day, a first-order death rate constant of 0.05/day, and they reach 1/2 of their maximum growth rate when the BOD5 concentration is
10 mg/l. The mean cell retention time of the solids is 4 days and sludge is processed on the belt filter press every 5 days.

Example 7.1 through 7.4 given below are based on the above data.

Example 7.1

What is the design volume of the aeration basin?

Solution

Assuming that 30% of the plant influent BOD5 is removed during primary sedimentation, this means that S_o = 444 mg/l × 0.70 = 310 mg/l.

$$Q_c = \frac{1}{t}$$

Thus, $$\frac{1}{Q_c} = \left[\frac{(Q_o \times Y)}{(V \times X)}(S_o - S)\right] - k_d$$

$$\frac{1}{4} = [\text{days}] = 33.75 \times 10^6 \left[\frac{-1}{d}\right] \times \frac{55}{100}\left[\frac{g}{g}\right] \times \left(310\left[\frac{\text{mg}}{l}\right] - 2\left[\frac{\text{mg}}{l}\right]\right)$$

$$V\ [l] \times 4300 \left[\frac{\text{mg}}{l}\right] - 0.05\left[\frac{1}{\text{day}}\right]$$

Solving for V, we get V = 5007558 l = 5,00,000 l.

Example 7.2

What is the plant's aeration period?

Solution

The plant's aeration period is the number of hours that the wastewater is aerated during the activated sludge process. This equals the hydraulic detention time of the biological reactor.

$$\theta = \frac{V}{Q} = \frac{5{,}000{,}000 \text{ l}}{33.75 \times 10^6 \text{ l/day}} = 0.15 \text{ day} = 3.6 \text{ hours}.$$

Example 7.3

How many kg of primary and secondary dry solids need to be processed daily from the treatment plant?

Solution

The amount of solids processed from the primary sedimentation tanks equals the difference in suspended solids concentrations measured across the sedimentation tanks multiplied by the plant flow rate. Thus,

33.75×10^6 l/day (200 mg SS/l – 100 mg SS/l) × kg/1,000,000 mg
= 3375 kg primary solids per day.

We are not provided with the concentration difference of suspended solids across the secondary sedimentation tanks so we can determine the amount of secondary solids produced daily in the same manner that we used for primary solids. However, careful examination of the expression of solids retention time shows that the term $Q_w X_w$ can be estimated as the following :

4 days = $V = \frac{X}{Q_w} \times X_w$ = 5,000,000 l (4,300 mg SS/l)/$Q_w \times X_w$

Solve for $Q_w X_w$ which equals 5375 kg or say 5400 kg secondary dry solids per day.

Example 7.4

Determine the F/M ratio (in units of lbs BOD5/lb MLSS-day) using data provided in the above example problem.

Solution

By definition,

$F/M = Q\,S_o/X\,V$ = [33.75×10^6 l/day × 310 mg/l)/[4,300 mgSS/l × 5,000,000 l] = 0.49 kg BOD5/kg MLSS-day

Various reactor configurations are available, each with its own set of advantages and disadvantages. The two basic types are plug flow (PF) and completely mixed flow (CMF) reactors. PF reactors offer a higher treatment efficiency than CMF reactors, but are less able to handle spikes in the BOD load. Other modifications of the process are based on the manner in which waste and oxygen are introduced to the system.

Operational Aspects of Activated Sludge Process

The main operational problem encountered in a system of this kind is sludge bulking, which can be caused by the absence of phosphorus, nitrogen and trace elements and wide fluctuations in pH, temperature and dissolved oxygen (DO). Bulky sludge has poor settleability and compactibility due to the excessive growth of filamentous micro-organisms. This problem can be controlled by chlorination of the return sludge. Conventional
activated-sludge processes and various modifications (Figures 7.13 to 7.15) are described below.

Conventional Plug Flow

Settled wastewater and recycled activated sludge enter the head of the aeration tank and are mixed by diffused air or mechanical aeration. Air application is generally uniform throughout the tank length. During the aeration period, adsorption, flocculation, and oxidation of organic matter occur. Activated-sludge solids are separated in a secondary settling tank. BOD removal efficiency varies between 85-95%.

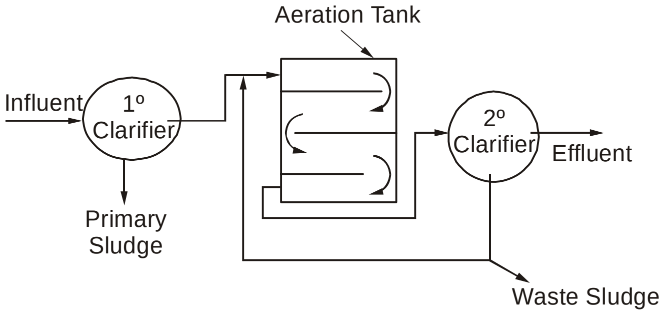


Figure 7.13 : Conventional Plug Flow Activated Sludge Process

Complete-mix Process

This is an application of the flow regime of a continuous-flow stirred tank reactor. Settled wastewater and recycled activated sludge are typically introduced at several points in the aeration tank. The organic load on the aeration tank and the oxygen demand are uniform throughout the tank length. BOD removal efficiency varies between 85-95%.

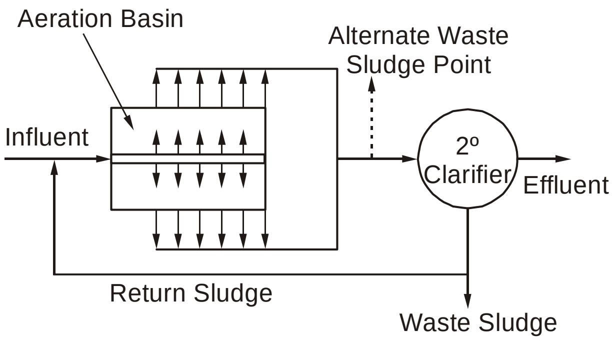


Figure 7.14 : Completely Mix Activated Sludge Process

Tapered Aeration

Tapered aeration is a modification of the conventional plug-flow process. Varying aeration rates are applied over the tank length, depending on the oxygen demand. Greater amounts of air are supplied to the head end of the aeration tank, and the amounts diminish as the mixed liquor approaches the effluent end. Tapered aeration is usually achieved by using different spacing of the air diffusers over the tank length.

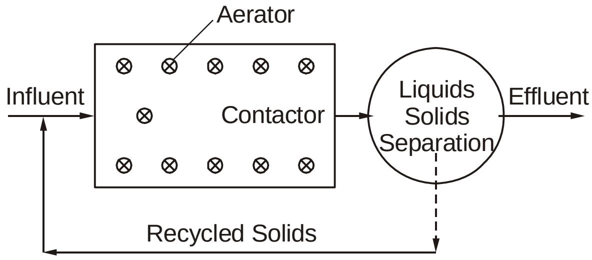


Figure 7.15 : Tapered Aeration Activated Sludge Process

Step-feed Aeration

Step feed is a modification of the conventional plug-flow process in which the settled waste-water is introduced at several points in the aeration tank to equalize the food to micro-organism (F/M) ratio, thus lowering peak oxygen demand. Three or more parallel channels are commonly used. Flexibility of operation is one of the important features of this process. BOD removal efficiency varies between 85-95%.

Contact Stabilization

Contact stabilization uses two separate tanks for the treatment of the wastewater and the stabilization of the activated sludge. The stabilized activated sludge is mixed with the influent (either raw or settled) wastewater in a contact tank. The mixed liquor is settled in a secondary settling tank and return sludge is aerated separately in a re-aeration basin for stabilization of the organic matter. Aeration volume requirements are typically 50% less than in the case of conventional plug flow. BOD removal efficiency varies between 80-90%.

Extended Aeration

The extended aeration process is similar to the conventional plug-flow process except that it operates in the endogenous respiration phase of the growth curve, which requires a low organic loading and long aeration time. The process is used extensively for prefabricated package plants for small communities. BOD removal efficiency varies between 75-95%.

High-Rate Aeration

High-rate aeration is a process modification in which high mixed liquor suspended solids (MLSS) concentrations are combined with high volumetric loadings. The combination allows high F/M ratios and low mean cell-residence times with relatively short hydraulic detention times. Adequate mixing is very important. BOD removal efficiency varies between 75-90%.

Oxidation Ditch

The oxidation ditch consists of a ring- or oval-shaped channel and is equipped with mechanical aeration devices (Figure 7.16). Screened wastewater enters the ditch, is aerated, and circulates about 0.25 to 0.35 m/s. Oxidation ditches typically operate in an extended aeration mode with long detention and solids retention times. Secondary sedimentation tanks are used for most applications. BOD removal efficiency varies between 75-95%.

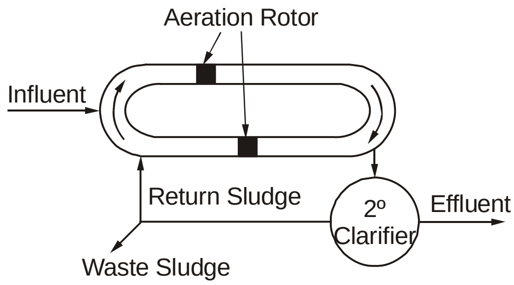


Figure 7.16 : Oxidation Ditch Activated Sludge Process

Aerated Lagoons

An aerated lagoon is a basin between 1 and 4 metres in depth in which wastewater is treated either on a flow-through basis or with solids recycling. The microbiology involved in this process is similar to that of the activated-sludge process. However, differences arise because the large surface area of a lagoon may cause more temperature effects than are ordinarily encountered in conventional activated-sludge processes. Wastewater is oxygenated by surface, turbine or diffused aeration. The turbulence created by aeration is used to keep the contents of the basin in suspension. Depending on the retention time, aerated lagoon effluent contains approximately one third to one half the incoming BOD value in the form of cellular mass. Most of these solids must be removed in a settling basin before final effluent discharges (Figure 7.17).

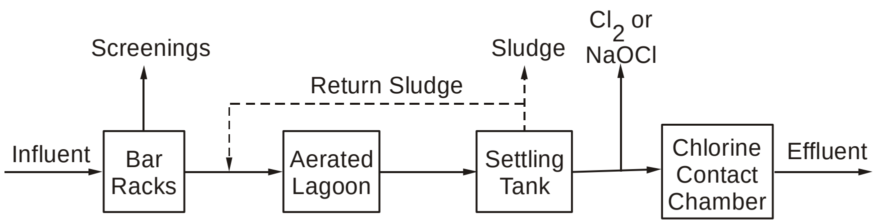


Figure 7.17 : Typical Flow Diagram for Aerated Lagoons

SAQ 4

(a) An activated sludge system is to be used for secondary treatment of 10000 m^3/d of municipal wastewater. After primary clarification, the BOD is 150 mg/l and it is desired to have not more than 5 mg/l of soluble BOD in effluent. A completely mixed reactor to be used and pilot plant analysis has established the following kinetic values : $Y = 0.5$ kg/kg, $k_d = 0.05\ d^{-1}$. Assuming MLSS concentration of 3000mg/l and an underflow concentration of 10000mg/l from secondary clarifier, determine

(i) the volume of reactor, and

(ii) the mass and volume of solids that must be wasted each day.

(b) Define F/M ratio and sludge bulking.

(c) Write short note on the following aspects of activated sludge processes.

(i) Step feed aeration

(ii) Contact stabilization

(iii) Extended aeration

(iv) Combined plug flow.

7.13.2 Trickling Filters

The trickling filter is the most commonly encountered aerobic attached-growth biological treatment process used for the removal of organic matter from wastewater. It consists of a bed of highly permeable medium to which organisms are attached, forming a biological slime layer, and through which wastewater is percolated. The filter medium usually consists of rock or plastic packing material. The organic material present in the wastewater is degraded by adsorption onto the biological slime layer. In the outer portion of that layer, it is degraded by aerobic micro-organisms. As the micro-organisms grow, the thickness of the slime layer increases and the oxygen is depleted before it has penetrated the full depth of the slime layer. An anaerobic environment is, thus, established near the surface of the filter medium. As the slime layer increases in thickness, the organic matter is degraded before it reaches the micro-organisms near the surface of the medium. Deprived of their external organic source of nourishment, these micro-organisms die and are washed off by the flowing liquid. A new slime layer grows in their place. This phenomenon is referred to as 'sloughing'. After passing through the filter, the treated liquid is collected in an underdrain system, together with any biological solids that have become detached from the medium (Figure 7.18). The collected liquid then passes to a settling tank where the solids are separated from the treated wastewater. A portion of the liquid collected in the underdrain system or the settled effluent is recycled to dilute the strength of the incoming wastewater and to maintain the biological slime layer in moist condition.

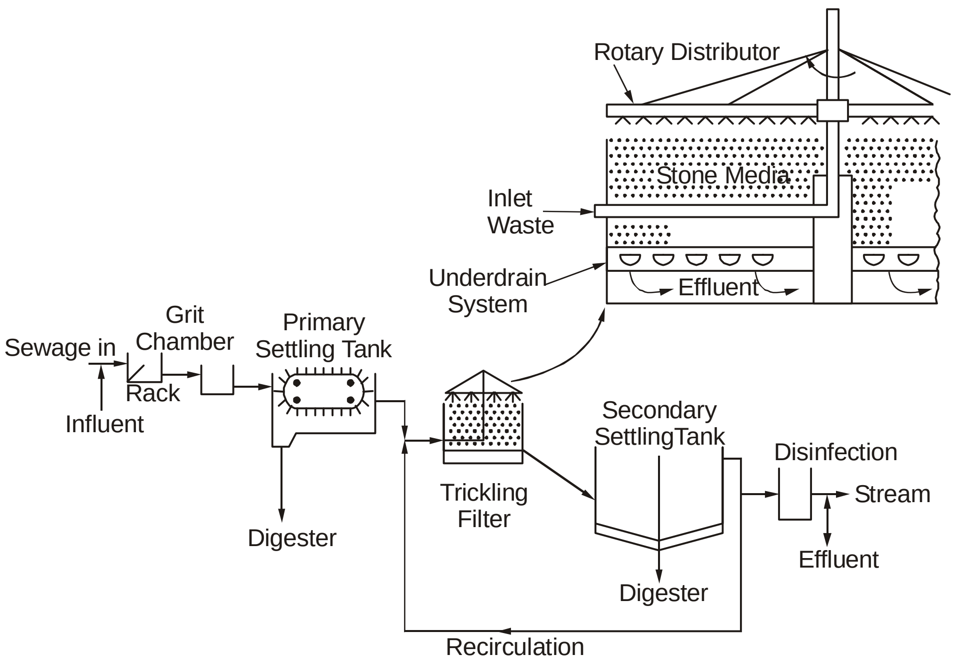


Figure 7.18 : Typical Flow Diagram for Trickling Filters

7.13.3 Rotating Biological Contactors

A rotating biological contactor (RBC) is an attached-growth biological process that consists of one or more basins in which large closely-spaced circular disks mounted on horizontal shafts rotate slowly through waste-water (Figure 7.19). The disks, which are made of high-density polystyrene or polyvinyl chloride (PVC), are partially submerged in the wastewater, so that a bacterial slime layer forms on their wetted surfaces. As the disks rotate, the bacteria are exposed alternately to wastewater, from which they adsorb organic matter, and to air, from which they absorb oxygen. The rotary movement also allows excess bacteria to be removed from the surfaces of the disks and maintains a suspension of sloughed biological solids. A final clarifier is needed to remove sloughed solids. Organic matter is degraded by means of mechanisms similar to those operating in the trickling filters process. Partially submerged RBCs are used for carbonaceous BOD removal, combined carbon oxidation and nitrification, and nitrification of secondary effluents. Completely submerged RBCs are used for denitrification.

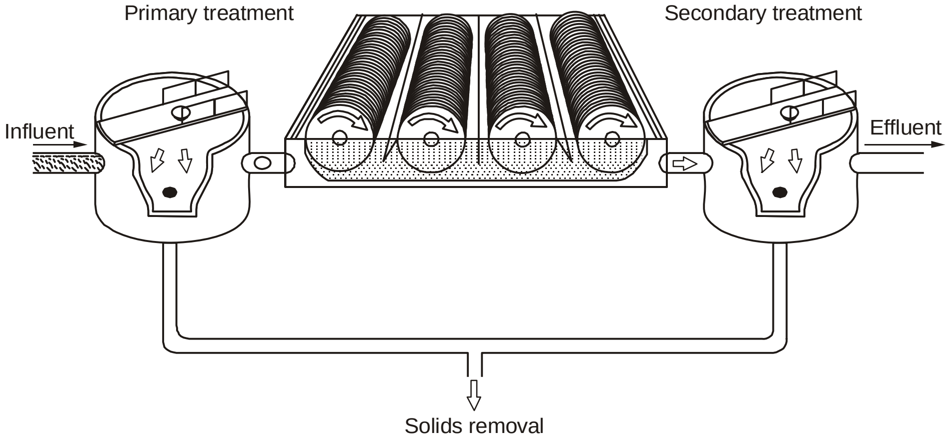


Figure 7.19 : RBC System Configuration

A typical arrangement of RBCs is shown in Figure 7.20. In general, RBC systems are divided into a series of independent stages or compartments by means of baffles in a single basin or separate basins arranged in stages. Compartmentalization creates a plug-flow pattern, increasing overall removal efficiency. It also promotes a variety of conditions where different organisms can flourish to varying degrees. As the wastewater flows through the compartments, each subsequent stage receives influent with a lower organic content than the previous stage; the system, thus, enhances organic removal.

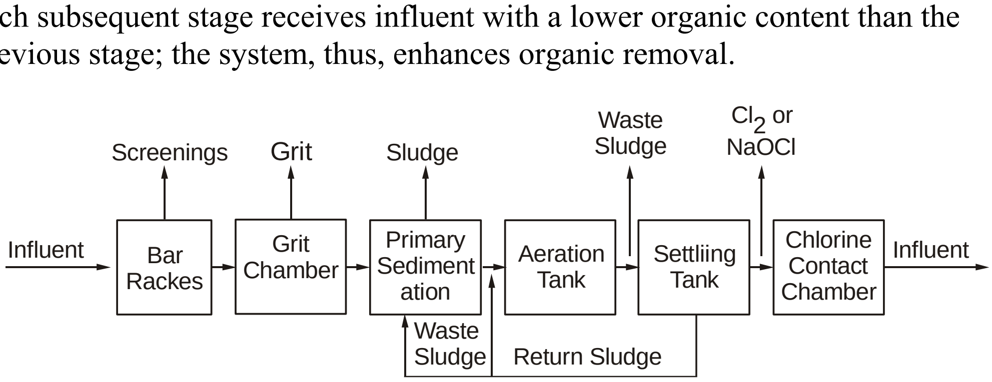


Figure 7.20 : Typical Flow Diagram for RBC Units

7.13.4 Stabilization Ponds

A stabilization pond is a relatively shallow body of wastewater contained in an earthen basin, using a completely mixed biological process without solids return. Mixing may be either natural (wind, heat or fermentation) or induced (mechanical or diffused aeration). Stabilization ponds are usually classified on the basis of the nature of the biological activity that takes place in them, as aerobic, anaerobic or aerobicanaerobic (Table 7.5). Aerobic ponds are used primarily for the treatment of soluble organic wastes and effluents from wastewater treatment plants. Aerobic-anaerobic (facultative) ponds are the most common type and have been used to treat domestic wastewater and a wide variety of industrial wastes. Anaerobic ponds, for their part, are particularly effective in bringing about rapid stabilization of strong concentrations of organic wastes. Aerobic and facultative ponds are biologically complex. The bacterial population oxidizes organic matter, producing ammonia, carbon dioxide, sulphates, water and other end products, which are subsequently used by algae during daylight to produce oxygen. Bacteria then use this supplemental oxygen and the oxygen provided by wind action to break down the remaining organic matter. Wastewater retention time ranges between 30 and 120 days. This is a treatment process that is very commonly found in rural areas because of its low construction and operating costs.

Table 7.5 : Types and Applications of Stabilization Ponds

Type of Pond	Common Name	Characteristics	Application
Aerobic	Low-rate pond	Designed to maintain aerobic conditions throughout the liquid depth	Treatment of soluble organic wastes and secondary effluents
	High-rate pond	Designed to optimize the production of algal cell tissue and achieve high yields of harvestable proteins	Nutrient removal, treatment of soluble organic wastes, conversion of wastes
	Maturation pond	Similar to low-rate ponds but very lightly loaded	Used for polishing effluents from conventional secondary treatment processes such as trickling filter or activated sludge
Aerobic-anaerobic (supplemental aeration)	Facultative pond with aeration	Deeper than high-rate pond; aeration and photosynthesis provide oxygen for aerobic stabilization in upper layers. Lower layers are facultative. Bottom layer of solids undergoes anaerobic digestion	Treatment of screened untreated or primary settled wastewater
Aerobic-anaerobic (oxygen from algae)	Facultative pond	As above, except without supplemental aeration. Photosynthesis and surface reaeration provide oxygen for upper layers	Treatment of screened untreated or primary settled wastewater
Anaerobic	Anaerobic lagoon, anaerobic pretreatment pond	Anaerobic conditions prevail throughout; usually followed by aerobic or facultative ponds	Treatment of municipal waste-water and industrial wastes
Anaerobic followed by aerobic anaerobic	Pond system	Combination of pond types described above. Aerobic-anaerobic ponds may be followed by an aerobic pond. Recirculation	Complete treatment of municipal wastewater and industrial wastes with high bacterial removal

		frequently used from aerobic to anaerobic ponds	

7.13.5 Completely Mixed Anaerobic Digestion

Anaerobic digestion involves the biological conversion of organic and inorganic matter in the absence of molecular oxygen to a variety of end-products including methane and carbon dioxide. A consortium of anaerobic organisms work together to degrade the organic sludges and wastes in three steps, consisting of hydrolysis of high-molecular-mass compounds, acidogenesis and methanogenesis.

The process takes place in an airtight reactor. Sludge is introduced continuously or intermittently and retained in the reactor for varying periods of time. After withdrawal from the reactor, whether continuous or intermittent, the stabilized sludge is reduced in organic and pathogen content and is non-putrescible. The two most widely used types of anaerobic digesters are standard-rate and high-rate. In the standard-rate digestion process, the contents of the digester are usually unheated and unmixed, and are retained for a period ranging from 30 to 60 days. In the high-rate digestion process, the contents of the digester are heated and mixed completely, and are retained, typically, for a period of 15 days or less. A combination of these two basic processes is known as the two-stage process, and is used to separate the digested solids from the supernatant liquor. However, additional digestion and gas production may occur. Anaerobic digesters are commonly used for the treatment of sludge and wastewaters with high organic content. The disadvantages and advantages of a system of this kind, as compared to aerobic treatment, stem directly from the slow growth rate of methanogenic bacteria. A slow growth rate requires a relatively long retention time in the digester for adequate waste stabilization to occur; however, that same slow growth means that only a small portion of the degradable organic matter is synthesized into new cells. Another advantage of this type of system is the production of methane gas, which can be used as a fuel source, if produced in sufficient quantities. Furthermore, the system produces a well-stabilized sludge, which can be safely disposed off in a sanitary landfill after drying or dewatering. On the other hand, the fact that high temperatures are required for adequate treatment is a major drawback.

7.13.6 Biological Nutrient Removal

Nitrogen and phosphorus are the principal nutrients of concern in wastewater discharges. Discharges containing nitrogen and phosphorus may accelerate the eutrophication of lakes and reservoirs and stimulate the growth of algae and rooted aquatic plants in shallow streams. Significant concentrations of nitrogen may have other adverse effects as well : depletion of dissolved oxygen in receiving waters, toxicity to aquatic life, adverse impact on chlorine disinfection efficiency, creation of a public health hazard and wastewater that is less suitable for reuse. Nitrogen and phosphorus can be removed by physical, chemical and biological methods. Biological removal of these nutrients is described below.

Nitrification-Denitrification

Nitrification is the first step in the removal of nitrogen by means of this process. Biological nitrification is the work of two bacterial genera: Nitrosomonas, which oxidize ammonia to the intermediate product nitrite, and Nitrobacter, which converts nitrite to nitrate. Nitrifying bacteria are sensitive organisms and are extremely susceptible to a wide variety of inhibitors such as high concentrations of ammonia and nitrous acid, low DO levels (< 1 mg/l), pH outside the optimal range (7.5-8.6), and so on.

Nitrification can be achieved through both suspended-growth and attached-growth processes. In suspended-growth processes, nitrification is brought about either in the same reactor that is used for carbonaceous BOD removal, or in a separate suspended-growth reactor following a conventional activated sludge treatment process. Ammonia is oxidized to nitrate with either air or high-purity oxygen. Similarly, nitrification in an attached-growth system may be brought about either in the same attached-growth reactor that is used for carbonaceous BOD removal or in a separate reactor. Trickling filters, rotating biological contactors and packed towers can be used for nitrifying systems.

Denitrification involves the removal of nitrogen in the form of nitrate by conversion to nitrogen gas under anoxic conditions. In denitrifying systems, DO is a critical parameter. Its presence suppresses the enzyme system needed for denitrification. The optimal pH lies between 7 and 8. Denitrification can be achieved through both suspended- and attached-growth processes. Suspended-growth denitrification takes place in a plug-flow type of activated-sludge system. An external carbon source is usually necessary for micro-organism cell synthesis, since the nitrified effluent is low in carbonaceous matter. Some denitrification systems use the incoming wastewater for this purpose. A nitrogen-gas-stripped reactor should precede the denitrification clarifier because nitrogen gas hinders the settling of the mixed liquor. Attached-growth denitrification takes place in a column reactor containing stone or one of a number of synthetic media upon which the bacteria grow. Periodic backwashing and an external carbon source are necessary in a system of this kind.

Phosphorus Removal

Phosphorus appears in water as orthophosphate (PO_4^{-3}), polyphosphate (P_2O_7), and organically bound phosphorus. Microbes utilize phosphorus during cell synthesis and energy transport. As a result, 10 to 30% of all influent phosphorus is removed during secondary biological treatment. More phosphorus can be removed if one of a number of specially developed biological phosphorus removal processes is used. These processes are based on the exposure of microbes in an activated-sludge system to alternating anaerobic and aerobic conditions. This stresses the micro-organisms, so that their uptake of phosphorus exceeds normal levels.

SAQ 5

Discuss working principle of Trickling Filter. Also draw a flow diagram in schematic form of a wastewater treatment plant that includes Trickling Filter.

7.14 SUMMARY

This unit describes the physical processes involved in wastewater treatment. In a typical wastewater treatment plan before secondary treatment, some physical treatment is always required. The physical treatment includes screens, grit chamber, communitors, flow equalization, oil and grease trap, and sedimentation. In some specific treatment physical treatment, like disinfections, adsorption and chemical precipitation are also required. This unit provides basic concept of these processes.

This unit discusses the various types of aerobic, anaerobic and facultative biological process and their application in wastewater treatment. Micro-organisms convert dissolved organic solids present in wastewater by aerobic and anaerobic processes selectively. Some of the most commonly used biological processes include, activated sludge process, trickling filters, stabilization ponds and anaerobic reactors. Also nutrient (N and P) removal processes are briefly discussed.

7.15 ANSWERS TO SAQs

SAQ 1

Refer Sections 7.1, 7.2 and 7.3.

SAQ 2

Refer Section 7.7.

SAQ 3

Refer Section 7.12.

SAQ 4

(a) Volume = 1611 m^3, Volume of solid wasted = 48.3 m^3/d.

(b) Refer Section 7.13.1.

(c) Refer Section 7.13.1.

SAQ 5

Refer Section 7.13.2.