13.7.5 Flow Patterns of Reactors

The flow pattern in the reactors depends on mixing conditions in them. This mixing in tern depends upon the shape of the reactor, energy spent per unit volume of the reactor, the size and scale of the unit, up-flow velocity of the liquid, rate of biogas generation (in an anaerobic reactors) or the rate of gas supplied (in an aerobic reactor), etc. Flow pattern affect the time of exposure to treatment and substrate distribution in the reactor. Depending upon the flow pattern the reactors can be classified as :
a) Batch reactors, b) Ideal Plug flow reactors, c) Ideal completely-mixed flow reactors,
d) Non –ideal, dispersed flow reactors, and e) series or parallel combinations of the reactors.

The hydraulic regime in the reactor can be defined with respect to the 'Dispersion number', which characterizes mixing condition in the reactor (Arceivala and Asolekar, 2007).

Dispersion Number = D/UL

Where,

D = Axial or longitudinal dispersion coefficient, L^2/t

U = Mean flow velocity along the reactor, L/t

L = Length of axial travel path, L

For ideal plug flow D/UL = 0, since, dispersion is zero by definition.

$D/UL \leq 0.2$ indicate the regime approaching plug flow conditions.

$D/UL \geq 3.0$ to 4.0 indicates approaching completely mixed conditions.

13.8 SEWAGE TREATMENT FLOW SHEET

The design of process flow sheet involves selection of an appropriate combination of various unit operations and unit processes to achieve a desired degree of contaminant removal. The selection of unit operations and processes primarily depends on the characteristics of the sewage and the required level of contaminants permitted in the treated effluents. The design of process flow sheet is important step in overall design of wastewater treatment and requires thorough understanding of the treatment units. It calls for optimization of wastewater treatment system coupled with stage wise optimal design of individual operation/ process to achieve a minimal cost design.

The main contaminants in domestic sewage, to be removed, are biodegradable organics, Suspended Solids (SS) and pathogens, with first two having been considered as the performance indicators for various treatment units. In general the objective of the domestic wastewater treatment is to bring down BOD less than 30 mg/L and SS less than 30 mg/L for disposal into inland water bodies.

The conventional flow sheet of sewage treatment plant consists of unit operations such as screening, grit removal, and Primary Settling Tank (PST), followed by unit process of aerobic biological treatment such as Activated Sludge Process (ASP) or Trickling Filter. The sludge removed from primary and secondary sedimentation tanks are digested anaerobically followed by drying of anaerobically digested sludge on sand drying beds. This process flow sheet is presented in Figure 13.1.

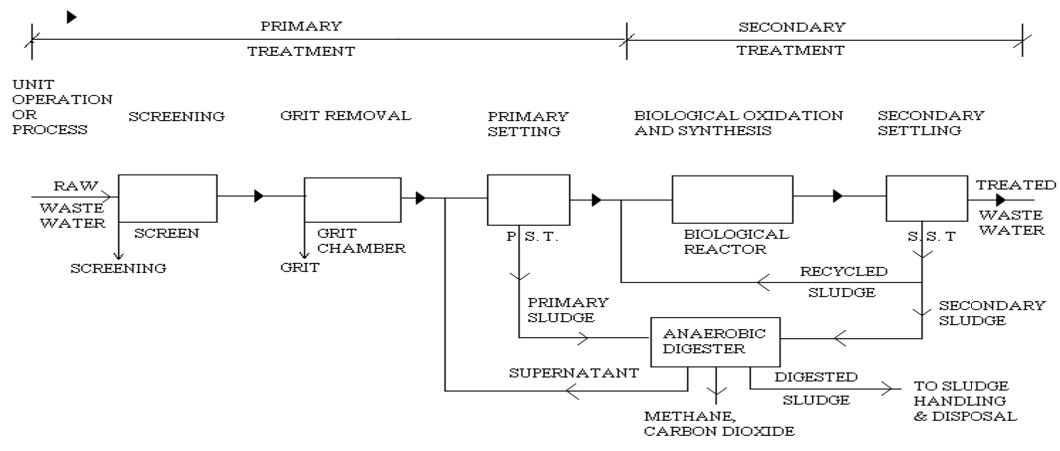
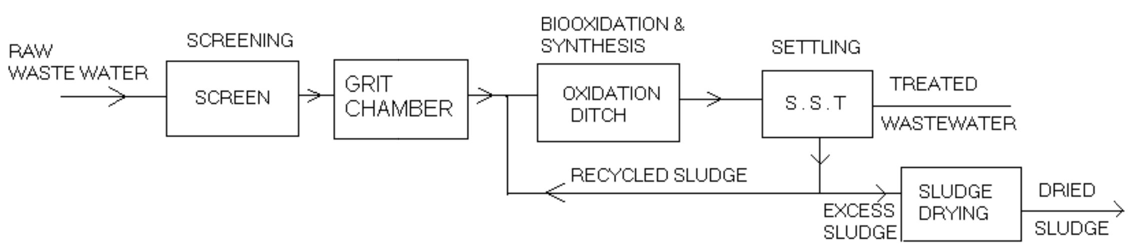
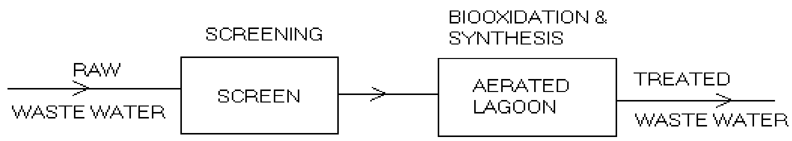


Figure 13.1 Process Flow-sheet of Conventional Domestic Sewage Treatment Plant

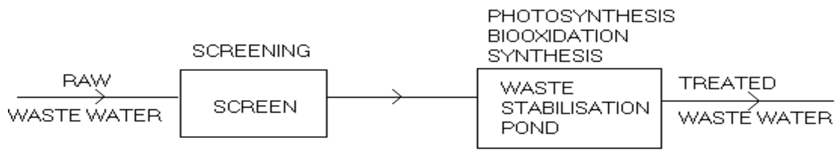
It is possible to replace the activated sludge process or trickling filter process by low cost treatment devices such as oxidation ditch, aerated lagoon or waste stabilization ponds. Such treatment devices obviate the necessity of some of the unit operations and processes like primary sedimentation and anaerobic digestion. Some of the process flow sheets are shown in Figure 13.2.



a) Process Flow sheet Incorporating Oxidation Ditch



b) Process Flow sheet Employing Aerated Lagoon



c) Process Flow sheet Employing Waste Stabilization Pond

Figure 13.2 Process flow sheet using oxidation ditch, aerated lagoon, and waste stabilization pond

With the better understanding of microbiology and biochemistry of anaerobic treatment, it is now feasible to treat dilute organic wastewater such as domestic wastewater directly through anaerobic treatment using recently developed innovative device such as Upflow Anaerobic Sludge Blanket Reactor (UASBR), Fluid–Bed Submerged Media Anaerobic Reactor (FB-SMAR) and Anaerobic Filter (AF) or Static–Bed SMAR (SB-SMAR) and Anaerobic Rotating Biological Contactor (AnRBC). Though, enough field data is to be generated as yet on their performance, it is generally reported that BOD_5 removal efficiencies may range from 60-80%. Consequently, post treatment will generally be required to achieve the prescribed effluent standards. The process flow sheet is depicted in Figure 13.3.

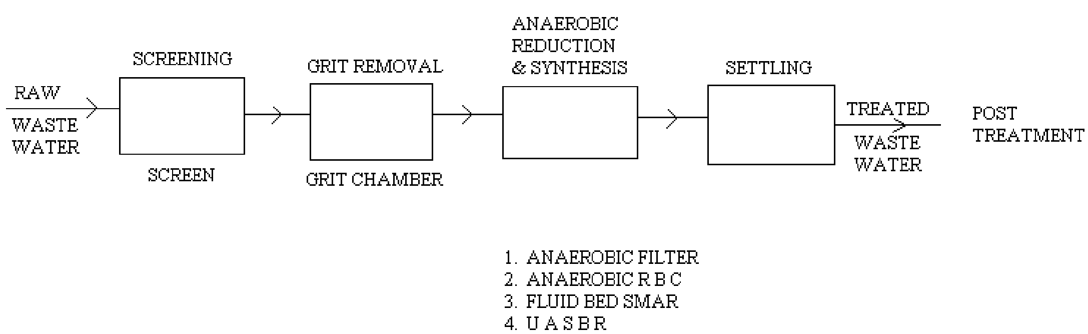


Figure 13.3 Process flow sheet employing anaerobic treatment system

13.9 PRIMARY TREATMENT UNITS

Primary treatment consists solely separating the floating materials and also the heavy settable organic and inorganic solids. It also helps in removing the oils and grease from the sewage. This treatment reduces the BOD of the wastewater by about 15 to 30%. The processes used are screening for removing floating papers, rages, cloths, etc., grit chambers or detritus tanks for removing grit and sand, and skimming tanks for removing oils and grease; and primary settling tank is provided for removal of residual suspended matter. The organic solids, which are separated out in the sedimentation tanks in primary treatment, are often stabilized by anaerobic decomposition in digestion tank or incinerated. After digestion the sludge can be used as manure after drying on sludge drying beds or by some other means.

13.9.1 Bar Screens

Bar screen is a set of inclined parallel bars, fixed at a certain distance apart in a channel. These are used for removing larger particles of floating and suspended matter. The wastewater entering the screening channel should have a minimum self-clearing velocity 0.375 m/sec. Also the velocity should not rise to such extent as to dislodge the screenings from the bars. The slope of the hand-cleaned screens should be between 30^0 and 45^0 with the horizontal and that of mechanically cleaned screens may be between 45^0 and 80^0. The submerged area of the surface of the screen, including bars and opening should be about 200% of the c/s area of the extract sewer for separate sewers and 300% for combined sewers. Clear spacing of bars for hand cleaned bar screens may be from 25 to 50 mm and that for mechanically cleaned bars may range from 15 mm to 75 mm. The width of the bars, facing the flow may be 8 mm to 15 mm and depth may vary from 25 mm to 75 mm, but sizes less than 8 x 25 mm are normally not used.

13.9.2 Grit Chamber

Grit chambers are designed to remove grit consists of sand, gravel, cinders or other inert solid materials that have specific gravity about 2.65, which is much greater than those of the organic solids in the wastewater. In this chamber particles settle as individual entities and there is no significant interaction with the neighboring particles. This type of settling is referred as free settling or zone-I settling. For proper functioning of the grit chamber, the velocity through the grit chamber should not be allowed to change in spite 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 horizontal flow grit chambers should be designed in such a way that under the most adverse conditions, all the grit particles of size 0.20 mm or more in diameter should reach the bed of the channel prior to reaching outlet end. The length of the channel depends on the depth required which again depends on the settling velocity. A minimum allowance of approximately twice the maximum depth should be given for inlet and outlet zones. An allowance of 20-50% of the theoretical length of the channel may also be given.

Width of grit chamber should be between 1 m to 1.5 m and depth of flow is normally kept shallow. For total depth of channel a free board of about 0.3 and grit space about 0.25 m should be provided. For larger plants two or more number of grit chambers in parallel may be used. In grit chambers the recommended detention time is about 30 to 60 seconds.

13.9.3 Skimming Tank

The floating solid materials such as soap, vegetables, debris, fruit skins, pieces of corks, *etc.* and oil and grease are removed from the wastewater in skimming tanks. A skimming tank is a chamber designed so that floating matter rises and remains on surface of the wastewater until removed, while the liquid flows continuously through outlet or partition below the water lines. The detention time in skimming tank is 3 minutes. To prevent heavy solids from settling at the bed, compressed air is blown through the diffusers placed in the floor of the tank. Due to compress air supply, the oily matters rise upward and are collected in the side trough, from where they are removed. In conventional sewage treatment plant separate skimming tank is not used and these materials are removed by providing baffle ahead of the effluent end of the primary sedimentation tank.

13.9.4 Primary Sedimentation Tank

Effluent of the grit chamber, containing mainly lightweight organic matter, is settled in the primary sedimentation tanks. The objective of treatment by sedimentation is to remove readily settleable solids and floating material and thus to reduce the suspended solids content when they are used as preliminary step to biological treatment, their function is to reduce the load on the biological treatment units.

The primary sedimentation tanks are usually designed for a flow through velocity of 1 cm/sec at average rate of flow. The detention period in the range of 90 to 150 minutes may be used for design. These tanks may be square, circular, or rectangular in plan with depth varying from 2.3 to 5 m. The diameter of circular tanks may be up to 40 m. The width of rectangular tank may be 10 to 25 m and the length may be up to 100 m. But to avoid water currents due to wind, length is limited up to 40 m. The slope of sludge hoppers in these tanks is generally 2:1 (vertical: horizontal). The slope of 1% is normally provided at the bed for rectangular tanks and 7.5 to 10% for circular tanks. This slope is necessary so that solids may slide to the bottom by gravity.

13.10 SECONDARY TREATMENT

The effluent from primary treatment is treated further for removal of dissolved and colloidal organic matter in secondary treatment. This is generally accomplished through biochemical decomposition of organic matter, which can be carried out either under aerobic or anaerobic conditions. In these biological units, bacteria's decompose the fine organic matter, to produce clearer effluent. The end products of aerobic decomposition are mainly carbon dioxide and bacterial cells, and that for anaerobic process are CH_4, CO_2 and bacterial cells.

The biological treatment reactor, in which the organic matter is decomposed (oxidized) by aerobic bacteria may consist of:

1) Filters (tricking filters),
2) Activated Sludge Process (ASP),
3) Oxidation ponds, *etc.*

The bacterial cells separated out in secondary setting tanks will be disposed by stabilizing them under aerobic or anaerobic process in a sludge digestion tank along with the solids settled in primary sedimentation tanks.

13.10.1 Trickling Filter

Trickling filters can be used for complete treatment for domestic waste and as roughing filter for strong industrial waste prior to activated sludge units. The primary sedimentation tank is provided prior to trickling filter so that the settleable solids in the sewage may not clog the filter. The trickling filter is followed by secondary settling tank for removal of settleable biosolids produced in filtteration process.

As the wastewater trickles through the filter media (consisting of rock 40 to 100 mm size or plastic media), a biological slime consisting of aerobic bacteria and other biota builds up around the media surface. Organic material in the sewage is absorbed on the biological slime, where they are partly degraded by the biota, thus increasing the thickness of the slime. Eventually there is a scouring of the slime and fresh slime layer begins to grow on the media. This phenomenon of scouring of the slime is called sloughing of the filter.

The trickling filters are classified as low rate and high rate depending on the organic and hydraulic loadings. Low rate filters are designed for hydraulic loading of 1 to 4 $m^3/m^2.d$ and organic loadings as 80 to 320 g BOD/m^3.d. The high rate trickling filters are designed for hydraulic loading of 10 to 30 $m^3/m^2.d$ (including recirculation) and organic loading of 500 to 1000 g BOD/m^3.d (excluding recirculation). Generally recirculation is not adopted in low rate filter and recirculation ratio of 0.5 to 3.0 or higher is used in case of high rate trickling filters. The depth of media varies from 1.0 to 1.8 m for high rate filters and 2.0 to 3.0 m for low rate filters. The bed of trickling filter is provided with slope 1 in 100 to 1 in 50. The under drainage system consists of ‘V’shaped or half round channels, cast in concrete floor during its construction. Revolving distributors are provided at top with two or four horizontal arms of the pipe having perforations or holes. These rotating arms remain 15 to 25 cm above the top surface of the media. The distribution arms are rotated by the electric motor or by back reaction on the arms by the wastewater, at about 2 rpm. The head of 30 to 80 cm of wastewater is required to rotate the arms.

13.10.2 Activated Sludge Process

It is aerobic biological treatment system. The settled wastewater is aerated in an aeration tank for a period of few hours. During the aeration, the microorganisms in the aeration tank stabilize the organic matter. In this process part of the organic matter is synthesized into new cells and part is oxidized to derive energy. The synthetic reaction followed by subsequent separation of the resulting biological mass and the oxidation reaction is the main mechanism of BOD removal in the activated sludge process.

The biomass generated in the aeration tank is generally flocculent and it is separated from the aerated wastewater in a secondary settling tank and is recycled partially to the aeration tank. The mixture of recycled sludge and wastewater in the aeration tank is referred as mixed liquor. The recycling of sludge helps in the initial built up of a high concentration of active microorganism in the mixed liquor, which accelerates BOD removal. Once the required concentration of microorganism in the mixed liquor has been reached its further increase is prevented by the regulating quantity of sludge recycled and wasting the excess sludge from the system.

Aeration units are main units of activated sludge process, the main aim of which is to supply oxygen to the wastewater to keep the reactor content aerobic and to mix up the return sludge wastewater thoroughly. The usual practice is to keep the detention period between 6 to 8 hours. The volume of aeration tank is also decided by considering the return sludge, which is about 25 to 50% of the wastewater volume.

Normally liquid depth provided should be between 3 and 4.5 m. A free board of 0.3 to 0.6 m is also provided. The mode of air supply in aeration tank can be either diffused air aeration, by supplementing compressed air from tank bottom, or by mechanical aerators provided at surface or by both diffused aeration and mechanical aerators. Depending on flow regime the activated sludge process can be classified as conventional (plug flow) and completely mixed activated sludge process. The modification of activated sludge process such as extended aeration is popularly used for treatment of wastewaters. The extended aeration is design for higher hydraulic retention time and low F/M ratio.

13.10.3 Secondary Settling Tank (SST)

Design of secondary settling is somewhat different than that of the primary settling tanks. In the secondary settling tank the function served is clarification as well as thickening of the sludge. This type of settling which takes place in secondary settling tank is refereed as zone settling followed by compression. The SST is designed for detention period of 1.5 to 2.5 h. The depth of the tank can be between 2.5 and 4.5 m. The area of the tank is to worked out on the basis of surface overflow rate, overflow rate for SST of trickling filter should be 15-25 $m^3/m^2.d$ and for SST of ASP 15-35 $m^3/m^2.d$ at average flow. The length of effluent weir should be such that the weir loading rate is less than 185 $m^3/m.d$.

13.10.4 Oxidation Ponds

Oxidation ponds are the stabilization ponds, which received partially treated sewage. It is an earthen pond dug into the ground with shallow depth. The pond should be at least 1.0 m deep to discourage growth of aquatic weeds and should not exceed 1.8 m. The detention time in the pond is usually 2 to 6 weeks depending upon sunlight and temperature. Better efficiency of treatment is obtained if several ponds are placed in series so that the sewage flows progressively from one to another unit until it is finally discharged.

The surface area of the pond may be worked out by assuming a suitable value of organic loading which may range from 150 –300 kg/ha/d or so in hot tropical countries like India. Each unit may have an area ranging between 0.5 to 1.0 hectare.

The length of the tank may be kept about twice the width. A free board of about 1 m may also be provided above a capacity corresponding to 20-30 days of detention period. Properly operated ponds may be as effective as trickling filter in reducing the BOD of sewage. The BOD removal efficiency of pond is up to 90% and coliform removal efficiency of pond is up to 99%.

13.10.5 Sludge Treatment

Sludge drying beds are commonly used in small wastewater treatment plants to dewater the sludge prior to final disposal. Two mechanisms are involved in the process, such as filtration of water through the sand, and evaporation of water from sludge surface. The filtered water is returned to the plant for treatment. The process is well suited to sludge, which have under gone proper aerobic or anaerobic digestion. Sludge from the conventional activated sludge, contacted stabilization, trickling filter, and rotating biological contactor processes usually contain a large amount of volatile solid, which tend to unpleasant odor problem. Therefore this method is generally not suitable for handling this sludge without prior stabilization, and digestion of sludge is essential prior to application of sludge on sludge drying beds.

A typical sludge drying bed consist of 15 to 30 cm of coarse sand layer underlain by approximately 20 to 45 cm of grade gravel ranging in size from 0.6 to 4 cm. Open jointed tubes of 10 to 15 cm diameter spaced at 2.5 to 6 cm are laid in the gravel to provide drainage for liquid passing through the bed. Sludge is applied to the drying bed in layer of 20 to 30 cm, depending upon local climatic conditions the sludge is allowed to dry for two to four weeks. Enclosing drying beds with glass can improve the performance of the dewatering process, particularly in cold or wet climates. In some cases only 67% of the area required for a bed is needed for an enclosed bed.

13.11 TERTIARY TREATMENT

This treatment is some times called as the final or advanced treatment and consists in removing the organic load left after secondary treatment for removal of nutrients from sewage and particularly to kill the pathogenic bacteria. This treatment which is normally carried out by chlorination is generally carried out for disposal of treated sewage in water for reuse of river water at downstream for water supplies. However, for other reuses tertiary treatment is required for further removal of organic matter, suspended solids, nutrients and total dissolved solids as per the needs.

The sewage treatment is generally confined up to secondary treatment only. Various physical chemical and biological processes are available for treatment, depending upon the particular requirements. The choice of treatment methods depends on several factors, including the disposal facilities available. Actually, the distinction between primary, secondary & tertiary treatment is rather arbitrary, since many modern treatment methods incorporate physical, chemical, and biological processes in the same operations.

The secondary treatment can be achieved by aerobic process or anaerobic process. Conventionally the aerobic process i.e. activated sludge process was used for sewage treatment. As a low cost treatment oxidation pond can also be used for sewage treatment. With the advent of the energy crises, the use of anaerobic process as substitutes for the traditional energy dependent activated process and large space required oxidation processes are being taken into consideration in greater depth. The application of anaerobic process for wastewater treatment is attractive only if large volumes of wastewater can be forced through the system in a relatively short period of time. This will give low hydraulic retention time and therefore anaerobic reactor becomes space efficient.

Today majority of wastewater treatment plants use aerobic metabolism for the removal of organic matter. The most well known aerobic processes are the activated sludge process, oxidation ditch, oxidation pond, trickling filter, and aerated lagoons. Stabilization ponds use both the aerobic and anaerobic mechanisms. In the recent years due to increase in power cost and subsequent increase in operation cost of aerobic process, more attention is being paid for the use of anaerobic treatment systems for the treatment of wastewater including sewage. At few places the anaerobic process such as Upflow Anaerobic sludge Blanket (UASB) is in use for treatment of sewage.

Questions

1. Describe broad characteristics of the untreated sewage.
2. What are the factors that are responsible for changing characteristics of sewage from place to place?
3. What are the pollutants that should be removed before the sewage is considered safe for discharging back to water body?
4. Describe the classification of the water treatment methods.
5. Describe different reactor types used in treatment of wastewaters.
6. What is the objective of primary and secondary treatment of sewage?
7. What is secondary treatment of sewage? What type of reactors are used to facilitate this treatment?