the greasy materials may congeal easily.

SEDIMENTATION

9.14. Necessity of Sedimentation in Treatment of Waste Waters

As discussed in the previous pages, the screens and the grit chambers do remove most of the floating materials (like paper, rags, cloth, wood, tree branches, etc.) and the heavy inorganic settleable solids from the sewage. However, a part of the suspended *organic solids* which are too heavy to be removed as floating matters, and too light to be removed by grit chambers (designed to remove only the heavy inorganic solids of size more than 0.2 mm, and of sp. gravity 2.65), are generally removed by the sedimentation tanks. *The sedimentation tanks are thus designed to remove a part of the organic matter from the sewage effluent coming out from the grit chambers.*

In a complete sewage treatment, the sedimentation is, in fact, carried out twice ; once before the biological treatment (*i.e. primary sedimentation*) and once after the biological treatment (*i.e. secondary sedimentation*). When chemical coagulants are also used for flocculating the organic matter during the process of sedimentation, the process is called *chemical precipitation* or *sedimentation aided with coagulation*. This is generally not used in modern days, as discussed, later.

Other sewage treatment units which work on the principle of sedimentation are : *Septic tanks, Imhoff tanks*, etc. Septic tanks and Imhoff tanks combine sludge digestion with sedimentation, whereas the sludge deposited in primary as well as in the secondary settling tanks, is separately digested in the *sludge-digestion tanks*.

9.15. Sedimentation Tanks

The clarification of sewage by the process of 'sedimentation' can be affected by providing conditions under which the suspended material present in sewage can settle out. This is brought about in specially designed tanks called sedimentation tanks.

Out of the three forces which control the settling tendencies of the particles (enumerated earlier), the two forces *i.e.* the velocity of flow, and the shape and size of the particles, are tried to be controlled in these settling tanks. The third force *i.e.* the viscosity of sewage or the temperature of sewage is left uncontrolled, as the same is not practically possible.

The velocity of flow can be reduced by increasing the length of travel, and by detaining the particles for a longer time in the sedimentation basin. The size and the shape of the particles can be altered by the addition of certain chemicals in water. These chemicals are called *coagulants*, and they make the sedimentation quite effective leading to the settlement of even very fine and colloidal particles. However, their use is not made in "Plain Sedimentation" (or generally called "sedimentation"), but is being made in the process called "chemical precipitation" or "sedimentation with coagulation". This will be discussed later.

Sedimentation basins are thus designed for effecting settlement of particles by reducing the flow velocity or by detaining the sewage in them. They are generally made of reinforced concrete and may be rectangular or circular in plan. Long narrow rectangular tanks with *horizontal flow* (Fig. 9.12*a*) are generally preferred to the circular tanks with *radial* or *spiral flow* (Fig. 9.12*b*).

The capacity and other dimensions of the tank should be properly designed, so as to effect a fairly high percentage of removal of the suspended organic material. A plain sedimentation tank under normal conditions may remove about 60 to 65% of the suspended solids, and 30 to 35% of the BOD from the sewage*.

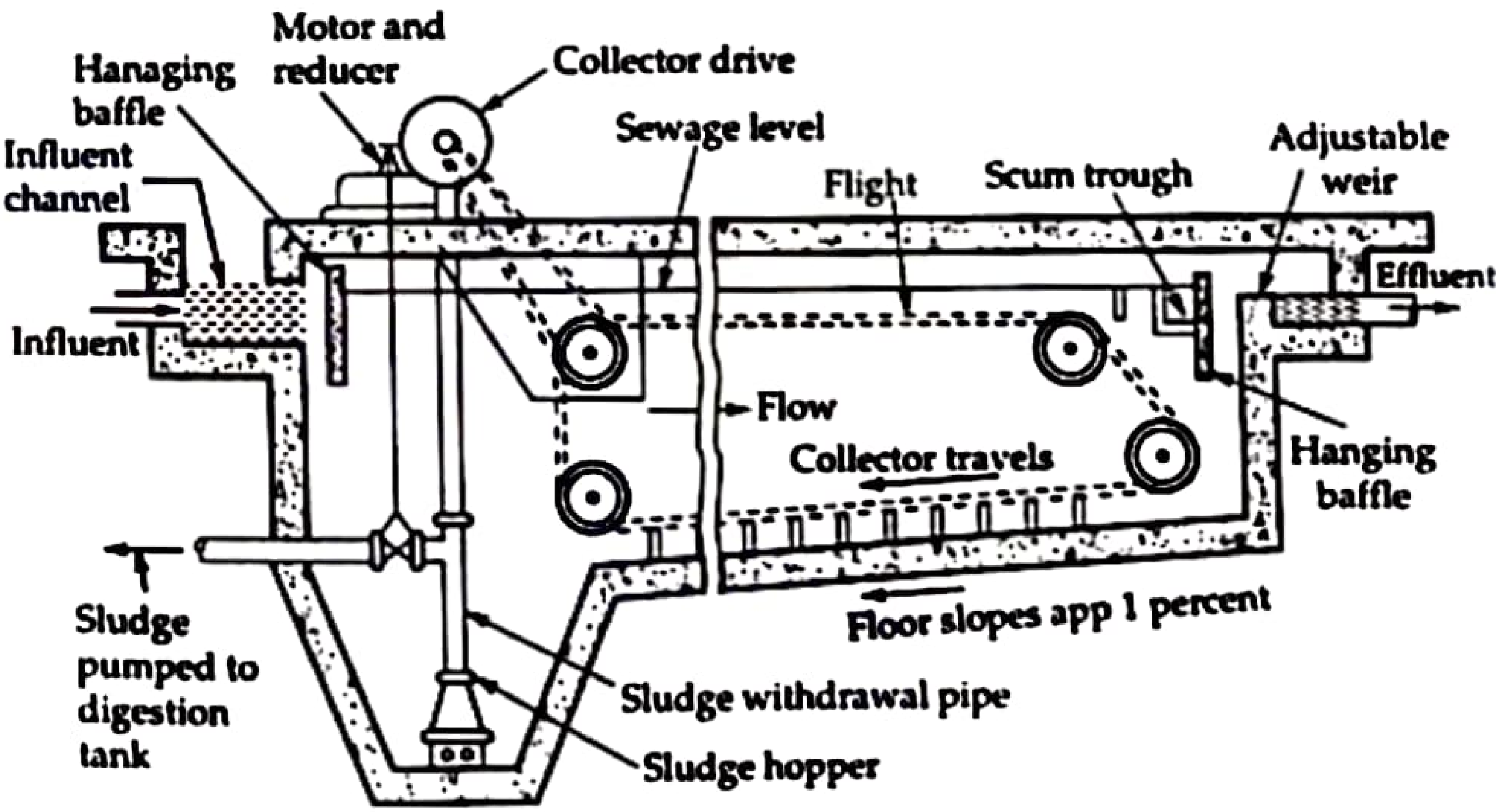

Fig. 9.12 (*a*) Rectangular sedimentation tank.

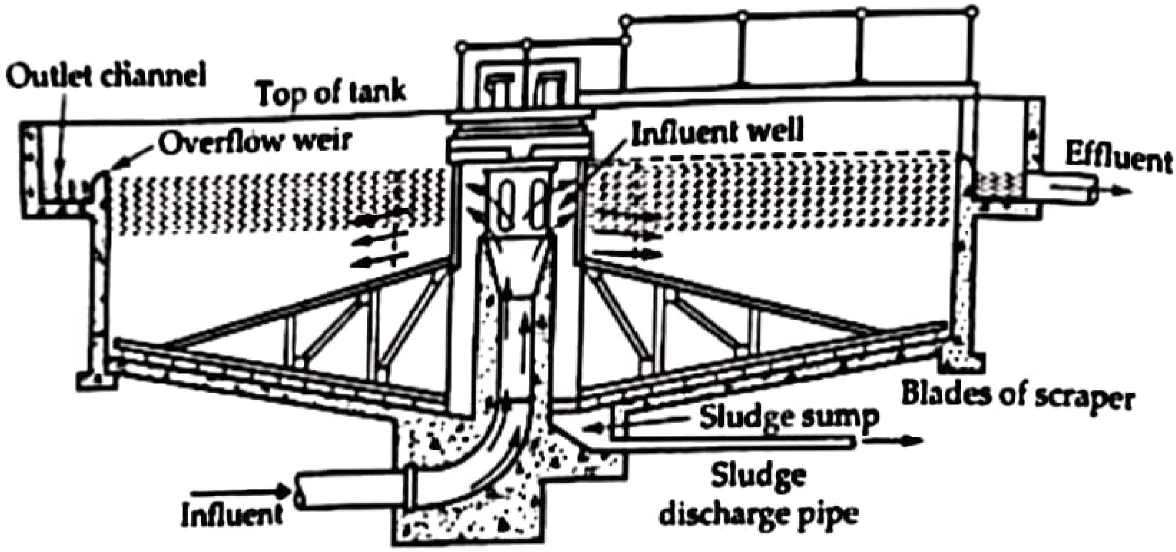

Fig. 9.12 (b) Circular sedimentation tank.

9.15.1. Types of Sedimentation Tanks. Sedimentation tanks may function either intermittently or continuously.

The Intermittent Settling tanks called ***quiescent type tanks*** are simple settling tanks which store sewage for a certain period and keep it in complete rest. After giving it a rest of about 24 hours, during which the suspended particles settle down to the bottom of the tank, the cleaner sewage from the top may be drawn off, and the tank be cleaned off the settled silt. The tank is again filled with raw sewage to continue the next operation. This type of tank, thus, functions intermittently, as a period of about 30 to 36 hours is required to put the tank again in working condition. This necessitates the commissioning of atleast two tanks. Such tanks are generally not preferred, because a lot of time and labour is wasted and more units are required, *They have, therefore, become completely obsolete these days.*

In a **continuous flow type** of a sedimentation tank, which is generally used in modern days, the flow velocity is only reduced, and the sewage is not brought to complete rest, as is done in an intermittent type. The working of such a tank is simple, as the water enters from one end, and comes out from the other end. The velocity is sufficiently reduced by providing sufficient length of travel. *The velocity is so adjusted that the time taken by the particle to travel from one end to another is slightly more than the time required for settlement of that particle.* The theory and design of such a tank is discussed below in details.

9.15.2. Design of a Continuous Flow Type of a Sedimentation Tank. In the theory which is applied to the design of such sedimentation basins, it is assumed that the sediment is uniformly distributed as the sewage enters the basin. In Fig. 9.13, let the water containing uniformly distributed sediment, enters the rectangular tank with a uniform velocity V. If Q is the discharge entering the basin, the flow velocity V is given by

$$V = \frac{Q}{BH} \qquad ...(9.25)$$

where B = Width of the tank or basin, and

H = Depth of sewage in the tank.

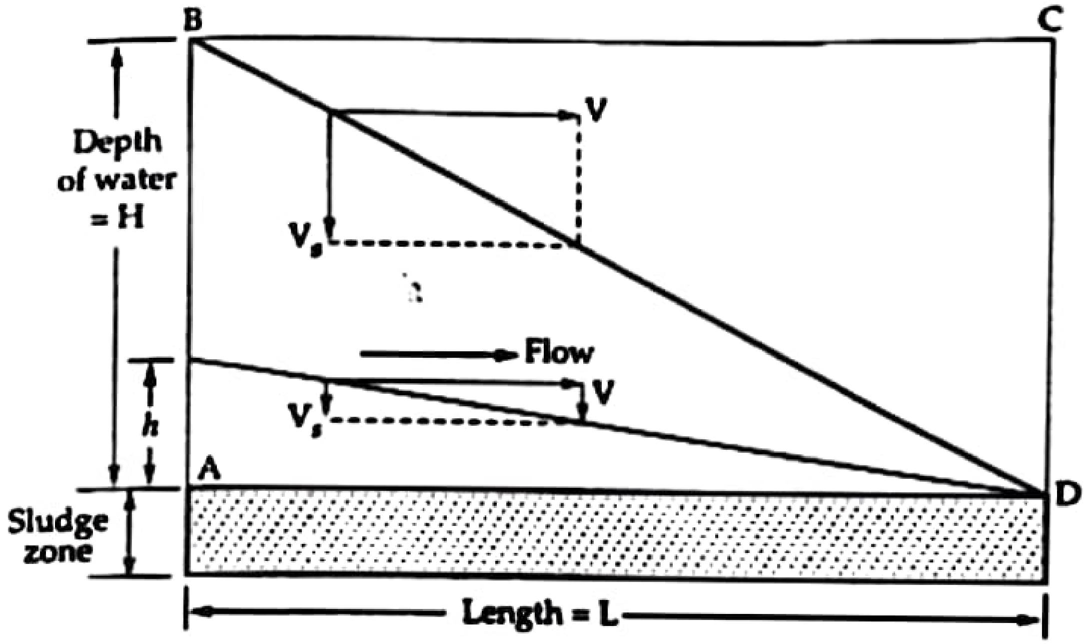

Fig. 9.13. Elevation or L-section of a rectangular sedimentation tank (Line diagram).

Now, every discrete particle is moving with a horizontal velocity V and a downward vertical velocity V_s. The resultant path is given by the vector sum of its flow velocity (V) and its settling velocity (V_s).

Now assuming that all those particles whose paths of travel are above the line BD, will pass through the basin, we have from geometric considerations :

$$\frac{V}{V_s} = \frac{L}{H} \qquad \text{...(9.26)}$$

or $$V_s = \frac{V.H}{L}.$$

But $$V = \frac{Q}{BH} \qquad \text{from equation (9.25)}$$

$$\therefore \quad V_s = \frac{Q}{BH}\cdot\frac{H}{L} \quad \text{or} \quad V_s = \frac{Q}{BL} \qquad \text{...(9.27)}$$

It shows that all those particles with a settling velocity equal to or greater than Q/BL will settle down, and be removed. In other words, no particle having a settling velocity more than or equal to Q/BL will remain suspended in such a tank.

It is mentioned above, that a particle having settling velocity greater than or equal to Q/BL will be removed. In fact, it is the case when the particle entering at full height H of the tank is considered. Truly speaking, even the smaller particles having settling velocities lower than Q/BL will also settle down, if they happen to enter at some other height h of the tank. In that case, when the particles are entering at some other height h of the tank, all those particles having their settling velocities $\geq \frac{h}{H}\frac{Q}{BL}$ will settle down.

If y_0 represents the number of particles of a given size that are settled out, and y being the total number of particles of that size, then the percentage of that particular sized particles which shall be removed is y_0/y ; and is equal to h/H for an assumed uniform distribution of particles. Hence, if 70% of particles of a given size are proposed to be removed in a settling tank, then the settling velocity of that sized particles must be kept $\geq \frac{70}{100} \cdot \frac{Q}{BL}$. In other words

$\frac{Q}{BL}$ must be kept less than equal to

$$\frac{100}{70} \times \text{settling velocity of that sized particle} \qquad ...(9.28)$$

It, therefore, follows that the quantity Q/BL *i.e.* the discharge per unit of plan area is a very important term for the design of continuous flow type of settling tanks ; and is known as **overflow rate or surface loading or overflow velocity.**

Normal values of overflow rates ranges between 40,000 to 50,000 litres/sq. m/day for plain* primary sedimentation tanks ; and between 50,000 to 60,000 litres/sq. m/day for sedimentation tanks using coagulants as aids ; and about 25,000 to 35,000 litres/sq. m/day for secondary sedimentation tanks.

Decreasing the overflow rate will lead to the settlement of even those particles which are having lower values of their settling velocities. *Hence, smaller particles will also settle down, if the overflow rate is reduced.* Further, with a given Q, the overflow rate can be reduced by increasing the plan area of the basin. It therefore, follows that an increase in the plan area (*i.e.* width × length) will increase the efficiency of sedimentation tank ; and *theoretically speaking, depth does not have any effect on the efficiency of sediment removal.* However, it is important for practical considerations, and also for making allowance for deposition of sludge and silt.

Usual values of effective depth (*i.e.* depth excluding the bottom sludge zone) *ranges between 2.4 to 3.6 m* (generally not exceeding 3 m).

Another important term, which is used in connection with the design of sedimentation basins, is its **detention time or detention period or retention**

---

*It is intended to remove 60 to 70% of the organic particles (sp. gr. 1.2) of size larger than 0.06 mm. The settling velocity for such particles is about 0.3 mm/sec or 1.2 m/hr. For affecting settlement, we have

$$\frac{Q}{BL} \leq \frac{100}{70} \times 1.2 \text{ m/hr (For affecting 70\% removal)}$$

or

$$\frac{Q}{BL} = 1.7 \text{ m/hr.}$$

or

$$\frac{Q}{BL} = 1.7 \text{ m}^3/\text{m}^2 \text{ plan area/hr.}$$

$$= 1700 \text{ litres/m}^2 \text{ of plan area/hr.}$$

$$= 1700 \times 24 \text{ litres/m}^2/\text{day}$$

$$= 40800 \text{ litres/m}^2/\text{day}$$

Similarly, for affecting 60% removal, it can be calculated that

$$\frac{Q}{BL} = 48{,}000 \text{ l/m}^2/\text{day}$$

Hence, surface loading adopted is about 40,000 l/m²/day to 50,000 l/m²/day for removing 70% to 60% of organic particles. Lesser is this value, higher is the removal.

period. The detention time (t) of a settling tank may be defined as the average theoretical time required for the sewage to flow through the tank. It is, thus, the time that would be required for the flow of sewage to fill the tank, if there was no outflow. In other words, it is the average time for which the sewage is detained in the tank. Hence, it is the ratio of the volume of the basin to the rate of flow (*i.e.* discharge) through the basin.

∴ Detention time, t, for a Rectangular tank

$$= \frac{\text{Volume of the tank}}{\text{Rate of flow}}$$

$$= \frac{B.L.H.}{Q} \qquad \text{...(9.29)}$$

Similarly, the detention time for a circular tank

$$= \frac{d^2(0.011\,d + 0.785\,H)}{Q} \qquad \text{...(9.30)}$$

where d = Dia of the tank

H = Vertical depth at wall or Side water depth.

The detention time for a sewage sedimentation tank usually ranges between 1 to 2 hours*. The lower value of detention period (*i.e.* 1 hour) is generally adopted when the activated sludge treatment is used in secondary treatment after the sedimentation ; and the higher and more normal value (*i.e.* 2 hours) is generally adopted when the trickling filters are used as the secondary treatment.

Larger detention periods will result in higher efficiency ; but too long a period induces septic conditions, and should be avoided. However, if the secondary sedimentation is to be avoided, a longer detention period of about $2\frac{1}{2}$ hours to 3 hours may be adopted.

The width of the tank is normally kept at about 6 m, and not allowed to exceed 7.5 m or so. The length of the tank is generally not allowed to exceed 4 to 5 times the width. The cross-sectional area of the sedimentation tank is such as to provide a horizontal flow velocity of about 0.3 m/minute. The total amount of flow from the tank within 24 hours, generally equals the maximum daily flow of sewage.

The maximum dia of a circular tank may be kept 60 m or so.

9.15.3. Short Circuiting in the Sedimentation Tanks. For the efficient removal of sediment in the sedimentation tanks, it is necessary that the flow is uniformly distributed throughout the cross-section of the tank. If currents, on the other hand, permit a substantial portion of the water to pass directly through the tank without being detained for the intended time, the flow is said to be *short circuited. Properly designed inlets and outlets near the entrance and the exit may reduce the short circuiting tendencies, and distribute the flow more evenly*. Moreover, relatively narrow tanks are less affected by inlet and outlet disturbances, and by currents caused by breezes.

*The settling velocity of the particles to be separated being of the order of 0.3 mm/sec or 1.2 m/hr., means that a detention period of 2 hrs will give satisfactory removal of intended solids (larger than 0.06 mm or so) in a tank of 2.4 m depth.

But however, in actual practice, certain amount of short circuiting will always exist, and, therefore, the actual average time taken by a batch of water in passing through a settling tank (called **flowing through period**) will always be less than the detention period, which is the corresponding theoretical time. The ratio of the 'flowing through period' to the 'detention period' is called the *Displacement efficiency.*

∴ Displacement efficiency (%)

$$= \frac{\text{Flowing through period}}{\text{Detention period}} \quad ...(9.31)$$

Note. In order to counteract the effects of short circuiting, it may be necessary to keep a high detention period or a smaller surface loading than that obtained from the theoretical considerations for obtaining the desired results.

9.15.4. Constructional Details of the Sedimentation Tanks. The following features of such tanks need special attention :

(*i*) **Inlet and Outlet Arrangement.** In order to reduce short circuiting, and to distribute the flow uniformly, proper arrangement must be made for smooth entry of water. A most suitable type of an inlet for a rectangular settling tank is in the form of a channel extending to full width of the tank, with a submerged weir type baffle wall, as shown in Fig. 9.14.

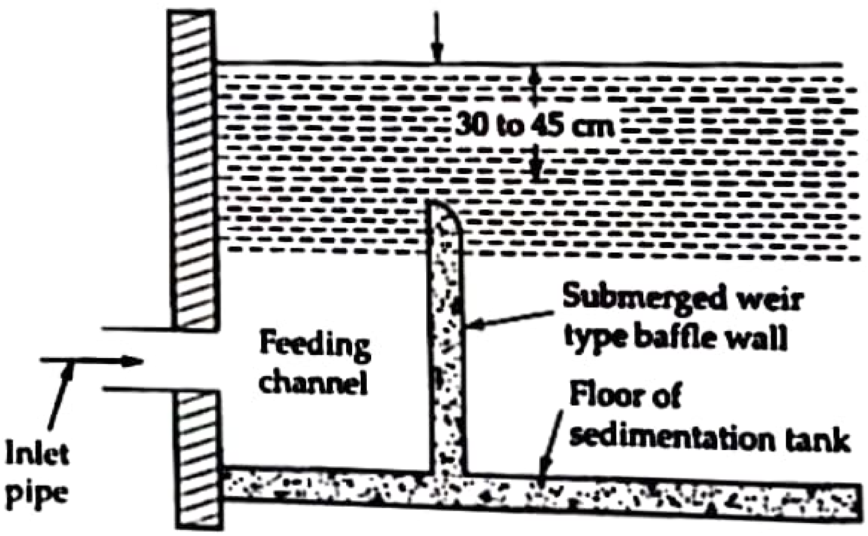

Fig. 9.14. Section of a 'Submerged type' or a 'Weir type' Inlet.

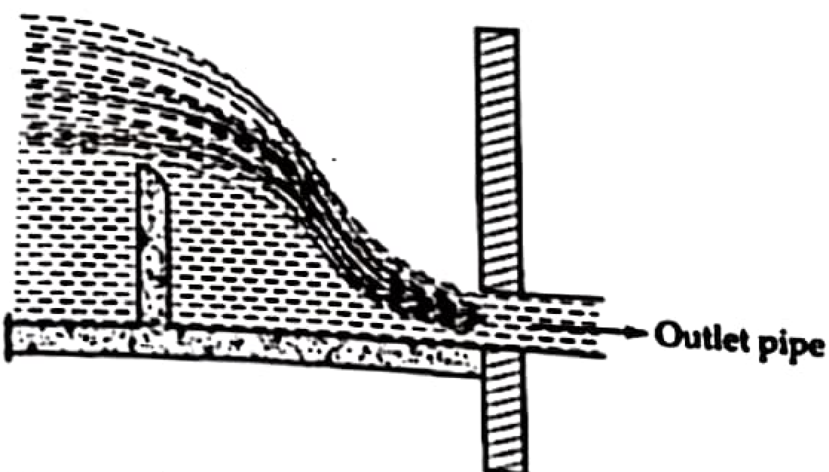

Fig. 9.15. Section of a 'submerged type' ...

A similar type of outlet arrangement is also used these days. It consists of an outlet channel extending for full width of the tank and receiving the water after it has passed over a weir, as shown in Fig. 9.15.

(*ii*) **Baffles.** Baffles are required to prevent the movement of organic matter and its escape along with the effluent ; and to distribute the sewage uniformly through the cross-section of the tank, and thus to avoid short circuiting. Both inlets and outlets are, therefore, protected by hanging baffles, 0 to 90 cm in front of them, and submerged 45 to 60 cm below the flow line, as shown in Fig. 9.11. Some other arrangement of placing baffles may be designed, but it should not be too complicated. Moreover, too many baffles may result in concentration of currents and is as bad as too less baffles are.

(*iii*) **Skimming Troughs.** When the amount of oils and greasy matter present in a sewage is small, it is generally uneconomical to provide a separate skimming tank. In such cases, a scum trough is generally provided in the sedimentation tank itself, near its outlet end, as shown in Fig. 9.12 (*a*).

In manually operated tanks, the skimmings that float to the surface may be pushed into the trough by squeezes with hand. Whereas, in mechanically operated tanks (such as in Fig. 9.12 *a*), the skimmings may be pushed by the same scraper blades which collect the sludge while moving along the bottom, and push the skimmings into the end trough, when they move near the surface along with the endless chain to which they are attached.

(*iv*) **Cleaning and Sludge Removal.** The suspended organic solids contained in sewage, settle down at the bottom of the sedimentation tank, and have to be removed periodically. The removal of the deposited sludge before it becomes stale and septic is necessary not only because it reduces the capacity of the tank and its detention period, but also because it leads to the evolution of foul gases formed due to the anaerobic decomposition of the settled organic matter. The sedimentation tanks are, therefore, cleaned from time to time at frequent intervals, either manually or they are provided with mechanical arrangements for cleaning.

In manual cleaning, the tank is, first of all, put out of service (thus needing duplicate tanks), and the supply of sewage stopped. The already contained sewage is drained off till the depth remains about 30 cm or so. The deposited sludge is now stirred and removed as a slurry through a separate pipe provided with a gate valve at the bottom of the tank. *Pick axes* and *pharaohs* may be used for displacing hard deposits. The removed sludge is first taken to a pump-sump, and then pumped into a sludge digestion tank for further treatment.

Modern sedimentation tanks, however, are generally provided with mechanical cleaning devices. Say for example, in Fig. 9.12 (*a*), the sludge is scraped by scrapers and brought to the hopper at the inlet end, and is removed daily or often. The scrapers can work either continuously or at any desired intervals of time. Similarly, in a circular tank (Fig. 9.12 *b*), the sludge is scraped and brought to the centre, and likewise removed. For tanks without mechanical sludge removing equipment, an additional minimum depth of about 0.8 to 1.2 m should be provided for storage of settled material, and is called the *sludge zone*.

Example 9.5. *Design a suitable rectangular sedimentation tank (provided with mechanical cleaning equipment) for treating the sewage from a city, provided with an assured public water supply system, with a max. daily demand of 12 million litres per day. Assume suitable values of detention period and velocity of flow in the tank. Make any other assumptions, wherever needed.*

Solution. Assuming that 80% of water supplied to the city becomes sewage, we have the quantity of sewage required to be treated per day (*i.e.* max. daily).

$$= 0.8 \times 12 \text{ million litres} = 9.6 \text{ M. litres}$$

Now assuming the detention period in the sewage sedimentation tank as 2 hours, we have

The quantity of sewage to be treated in 2 hours *i.e.* the capacity of the tank required

$$Q = \frac{9.6}{24} \times 2 \text{ M. litres} = 0.8 \text{ M litres} = 800 \text{ cu. m.}$$

Now, assuming that the flow velocity through the tank is maintained at 0.3 m/minute ; we have

The length of the tank required

$$= \text{Velocity of flow} \times \text{Detention period}$$

$$= 0.3 \times (2 \times 60) \text{ m} = 36 \text{ m.}$$

Cross-sectional area of the tank required

$$= \frac{\text{Capacity of the tank}}{\text{Length of the tank}} = \frac{800}{36} \text{ m}^2 = 22.2 \text{ m}^2.$$

Assuming the water depth in the tank (*i.e.* effective depth of tank) as 3 m, The width of the tank required

$$= \frac{\text{Area of X-section}}{\text{Depth}} = \frac{22.2}{3} = 7.4 \text{ m.}$$

Since the tank is provided with mechanical cleaning arrangement, no extra space at bottom is required for sludge zone.

Now, assuming a free-board of 0.5 m, we have

The overall depth of the tank

$$= 3 + 0.5 = 3.5 \text{ m.}$$

Hence, a rectangular sedimentation tank with an overall size of 36 m × 7.4 m × 3.5 m can be used.

[**Note.** This satisfies the requirements like : length ≯ 4 to 5 times the width ; and the width not more than 7.5 m or so ; the depth between 2.4 to 3.6 m, etc.]. **Ans.**

Alternatively,

Instead of assuming the depth, we may assume an overflow rate, say as 40,000 litres/m²/day.

$$\therefore \quad \frac{Q}{BL} = 40{,}000 \text{ litres/m}^2\text{/day}$$

But $Q = 9.6$ M. litres/day $= 9.6 \times 10^6$ litres/day

$$\therefore \quad BL = \frac{Q}{40{,}000} = \frac{9.6 \times 10^6}{40{,}000} \text{ m}^2 = 240 \text{ m}^2$$

or $$B = \frac{240}{L} = \frac{240}{36} = 6.67 \text{ m ; Say } \mathbf{6.7\ m}.$$

$\therefore$ The depth required

$$= \frac{\text{Area of X-section}}{\text{Width}} = \frac{22.2}{6.7} = 3.3 \text{ m}.$$

Hence, we can alternatively use a tank of dimensions 36 m × 6.7 m × (3.3 + 0.5 m) overall depth *i.e.* 36 m × 6.7 m × 3.8 m size. **Ans.**

Example 9.6. *Design a circular settling tank unit for a primary treatment of sewage at 12 million litres per day. Assume suitable values of detention period (presuming that trickling filters are to follow the sedimentation tank), and surface loading.*

Solution. Assuming the normal detention period for such cases as 2 hr, and surface loading as 40,000 litres/sq. m/day ; we have

The quantity of sewage to be treated per 2 hours

$$= 12 \text{ M. litres} \times \frac{2}{24} = 1 \text{ M. litres} = 1000 \text{ m}^3.$$

$\therefore$ Capacity of tank = 1000 m³.

Now, surface loading

$$= \frac{Q}{\text{Surface area of tank}} = \frac{Q}{\frac{\pi}{4}\cdot d^2}$$

or $$40{,}000 = \frac{12 \times 10^6}{\frac{\pi}{4}\cdot d^2}$$

where d is the dia. of the tank

or $$\frac{\pi}{4}\cdot d^2 = \frac{12 \times 10^6}{40{,}000}$$

or $$d = \sqrt{\frac{300 \times 4}{\pi}} = 19.55 \text{ m Say } \mathbf{19.6\ m}.$$

Now, effective depth of tank

$$= \frac{\text{Capacity}}{\text{Area of X-section}} = \frac{1000}{\frac{\pi}{4} \times (19.6)^2} = \frac{1000}{302}$$

$$= 3.2 \text{ m. (Say).}$$

Hence, use a settling tank with 19.6 m dia. and 3.2 m water depth (with free board of 0.3 m extra depth). **Ans.**

SEDIMENTATION AIDED WITH COAGULATION
(Type II. Sedimentation)

9.16. Chemical Precipitation and Coagulation

Very fine suspend particles, present in wastewaters, which cannot be removed in plain sedimentation, may sometimes, be settled by increasing their size by changing them into flocculated particles. For this purpose, a chemical compound (like ferric chloride, ferric sulphate, alum, chlorinated copperas, etc.) called *coagulant*, is added to the wastewater, which on thorough mixing, forms a gelatinous precipitate, called *floc*. The fine mud particles and other colloidal matter present in wastewater get absorbed in these flocs, forming the bigger sized flocculated particles. The process of addition and mixing of chemical is called coagulation. The coagulated sewage is then made to pass through sedimentation tank, where the flocculated particles settle down, and get removed.

The process of coagulation of sewage is similar to that of water, as described thoroughly in "Environmental Engg. Vol. I—Water Supply Engineering" (chapter 9). The purpose, principle, feeding and mixing of coagulants and their chemical reactions have been discussed at length in that chapter. **Since the coagulation of sewage is seldom adopted in modern days,** *we shall not repeat the entire coagulation process here in this volume*. The readers may, however, refer to volume 1, in special needs.

The characteristics and efficiency of the important coagulants used in sewage treatment are, however, given in Table 9.5.

9.17. Merits and Demerits of Coagulation Process in Sewage Treatment

As pointed out earlier, the coagulation process is generally not adopted in modern sewage treatment plants, mainly because of the following reasons :

(1) More advanced methods of sewage treatment based on biological actions are available these days, and they are preferred to coagulation.

(2) The coagulation process has various disadvantages, such as discussed below :

Disadvantages or Demerits of Coagulation in Sewage Treatment

(*i*) The biological secondary treatments used these days for treating sewage are complete in themselves, and do not require coagulation. Moreover, coagulation rather makes some of these processes more difficult.

(*ii*) The chemicals used in coagulation react with sewage, and during these reactions, they destroy certain micro-organisms, which are helpful in digestion of the sludge, thus creating difficulties in sludge digestion.

(*iii*) Cost of chemicals is added to the cost of sedimentation, without much use, and thereby making the treatment costlier.

(*iv*) The process of coagulation and subsequent sedimentation produces larger quantities of sludge than that produced in plain sedimentation, and thus adding to the problem of sludge disposal.

(*v*) The process of coagulation requires skilled supervision and handling of chemicals.

In view *of all these disadvantages, the coagulation of sewage has become obsolete these days. It may still, however, be adopted in certain special cases, such as* :

(*a*) For treating sewage from industries, using some specific chemicals in their processes.

Table 9.5. Properties of Important Coagulants Used in Sewage Treatment

S. No.	*Name of coagulant*	*B.O.D. removed as percentage of total present*	*Suspended solids removed as percentage of total present*	*Dosage required in ppm*	*pH value required for proper functioning*	*Remarks*
1.	**Ferric chloride**	80—90	90—95	25—35	5.5 to 7.0	This cogulant is widely used for sewage treatment*, wherever, coagulation is adopted.
2.	**Ferric sulphate with lime**	60	80	35—40	8.0 to 8.5	Ferric sulphate has been found to be more effective than chlorinated copperas, if used in conjunction with lime. *Hence ferric chloride and ferric sulphate are mainly used, as the main coagulants in sewage, if at all coagulation is adopted.*
3.	**Alum**	60	80	40—90	6 to 8.5	It is generally not used in sewage** although used for treating water supplies on a large scale.
4.	**Chlorinated copperas**	70—80	80—90	35—80	5.5 to 7.0 and 9.0 to 9.5	This coagulant is effective for producing sludge for activated sludge process.

*Ferric chloride forms a dense heavy floc, which settles rapidly. The sludge formed is also not so bulky, and can be digested or dewatered easily. However, it is corrosive in nature and requires care in storing and handling.

**Alum, although cheap and easy to handle, yet is not used in sewage treatment, because it forms a spongy floc, which settles slowly. Moreover, the volume of sludge produced is also large.

W kg of solids will make

$$= \frac{100 . W}{(100 - p_1)} \text{ kg of wet sludge.}$$

or Wt. of sludge produced $= \frac{100 . W}{(100 - p_1)}$ kg

∴ If γ_s is the unit wt. of sludge, in kg/m³, then

Vol. of sludge produced $= \frac{100 . W}{(100 - p_1)} . \frac{1}{\gamma_s}$ m³.

or $$V_1 = \frac{100 . W}{100 - p_1} . \frac{1}{\gamma_s}. \quad ...(i)$$

At moisture content of p (per cent), similarly, we have

Vol. of sludge produced $(V) = \frac{100 . W}{100 - p} . \frac{1}{\gamma_s}$ m³

or $$V = \frac{100 . W}{100 - p} . \frac{1}{\gamma_s} \quad ...(ii)$$

From equation (*i*), we have

$$W = \frac{(100 - p_1) V_1 . \gamma_s}{100}. \quad ...(iii)$$

From equation (*ii*), we have

$$W = \frac{(100 - p) V . \gamma_s}{100}. \quad ...(iv)$$

Equating (*iii*) and (*iv*), we get

$$\frac{(100 - p_1) V_1 . \gamma_s}{100} = \frac{(100 - p) V . \gamma_s}{100}$$

or $$\boxed{V = V_1 \left[\frac{(100 - p_1)}{(100 - p)}\right]. \quad \textbf{Ans.}} \quad ...(9.38)$$

Example 9.19. *The moisture content of a sludge is reduced from 95 to 90% in a sludge digestion tank. Find the percentage decrease in the volume of sludge.*

Solution. Using Eqn. (9.38), we have

$$V = V_1 \left[\frac{100 - p_1}{100 - p}\right]$$

or $$V = V_1 \left[\frac{100 - 95}{100 - 90}\right] = V_1 \times \frac{5}{10} = \frac{V_1}{2}$$

Thus, the volume at 90% moisture will be half of that at 95% moisture. Hence, the percentage decrease in moisture will be 50%. **Ans.**

9.26. Sludge Digestion Process

As pointed out earlier, the sludge withdrawn from the sedimentation basins contains a lot of putrescible organic matter, and if disposed of without any treatment, the organic matter may decompose, producing foul gases and a lot of nuisance, pollution, and health hazards. In order to avoid such pollutions, the sludge is, first of all, *stabilised by decomposing the organic matter under controlled anaerobic conditions**, and then disposed of suitably after drying on drying beds, etc. The process of stabilisation is called the *sludge digestion* ; and the tank where the process is carried out is called the *sludge digestion tank*. In a sludge digestion process, the sludge gets broken into the following three forms :

(*i*) **Digested sludge.** It is a stable humus like solid matter, tary black in colour, and with reduced moisture content, and, is therefore, having reduced volume (about $\frac{1}{3}$ times the undigested sludge volume). Moreover, the quality of digested sludge is much better than that of the undigested sludge, and it is free of pathogenic bacteria which are killed in the digestion process. It may still, however, contain cysts and eggs of bacteria, protozoa and worms.

(*ii*) **Supernatant liquor.** It includes the liquified and finely divided solid matter, and is having high BOD (about 3000 ppm).

(*iii*) **Gases of decomposition.** Gases like methane (65 to 70%), carbon dioxide (30%), and traces of other inert gases like nitrogen, hydrogen sulphide, etc. are evolved. They may be collected (particularly the methane which has a high calorific value) and used as a fuel.

The sludge gas, having 70% methane, has a fuel value of about 5800 kilo calorie/cu. m (*i.e.* 650 Btu per cu. ft. app.). The amount of gas produced, on an average, is about 0.9 cu. m. per kg of volatile solids reduced in digestion. The gas produced thus varies with the sewage produced, and works out to about 14 to 18 litres per capita per day (usually 17 *l/c/d*).

The digested sludge is *dewatered, dried up, and* used as fertiliser ; while the gases produced are also used for fuel or for driving gas engines. The supernatant liquor contains about 1500 to 3000 ppm of suspended solids ; and is, therefore, re-treated at the treatment plant along with the raw sewage.

9.27. Stages in the Sludge Digestion Process

Three distinct stages have been found to occur in the biological action involved in the natural process of sludge digestion. These stages are :

(*i*) *Acid fermentation ;*

(*ii*) *Acid regression ;* and

(*iii*) *Alkaline fermentation.*

These stages are briefly summarised here :

(*i*) **Acid Fermentation Stage or Acid Production Stage.** In this first stage of sludge digestion, the fresh sewage-sludge begins to be acted upon by *anaerobic and facultative bacteria,* called **acid formers.** These organisms solubilize the organic solids through *hydrolysis*. The soluble products are then fermented to volatile acids and organic alcohols of low molecular weight like propionic acid, acetic acid, etc. Gases like methane, carbon dioxide and

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*40 to 60% of the organic solids are converted by bacteria into carbon dioxide and methane gases. The organic matter which remains, is chemically stable and practically odourless, and contains 90 to 95% moisture.

hydrogen sulphide are also evolved. *Intensive acid production makes the sludge highly acidic, and lowers the pH value to less than 6. Highly putrefactive odours are evolved during this stage, which continues for about 15 days or so* (at about 21°C). BOD of the sludge increases to some extent, during this stage.

(*ii*) **Acid-Regression Stage.** In this *intermediate stage*, the volatile organic acids and nitrogenous compounds of the first stage, are attacked by the bacteria, so as to form acid carbonates and ammonia compounds. Small amounts of hydrogen sulphide and carbon-dioxide gases are also given off. The decomposed sludge has a very offensive odour, and its pH value rises a little, and to be about 6.8. The decomposed sludge, also, entraps the gases of decomposition, becomes foamy, and rises to the surface to form scum. *This stage continues for a period of about 3 months or so* (at about 21°C). BOD of the sludge remains high even during this stage.

(*iii*) **Alkaline Fermentation Stage.** In this *final stage* of sludge digestion, more resistant materials like proteins and organic acids are attacked and broken up by anaerobic bacteria, called **methane formers**, into simple substances like ammonia, organic acids and gases. *During this stage, the liquid separates out from the solids, and the digested sludge is formed.* This sludge is granular and stable, and does not give offensive odours. (It has a musty earthy odour). This digested sludge is collected at the bottom of the digestion tank, and is also called **ripened sludge**. Digested sludge is alkaline in nature. The pH value during this stage rises to a little above 7 (about 7.5 or so) in the alkaline range. *Large volumes of methane gas (having a considerable fuel value) alongwith small amount of carbon dioxide and nitrogen, are evolved during this stage. This stage extends for a period of about one month or so (at about 21°C). The BOD of the sludge also rapidly falls down during this stage.*

It is, thus, seen that several months (about $4\frac{1}{2}$ months or so) are required for the complete process of digestion to take place under natural uncontrolled conditions at about 21°C. This period of digestion is, however, very much dependent upon the temperature of digestion, and other factors. If these factors are controlled, quicker and effective digestion can be brought about, as discussed below.

9.28. Factors Affecting Sludge Digestion and Their Control

The important factors which affect the process of sludge digestion, and are, therefore, controlled in a digestion tank, are :

1. *Temperature ;*
2. *pH value ;*
3. *Seeding with digested sludge ; and*
4. *Mixing and stirring of the raw sludge with digested sludge.*

Besides these important factors, certain other minor conditi... like ... quality