11. PRIMARY SEDIMENTATION TANK

After grit removal in grit chamber, the wastewater containing mainly lightweight organic matter is settled in the primary sedimentation tank (PST). Due to involvement of many unknown parameters under settling of light weight, sticky, and non regular shaped particles, the classical laws of sedimentation such as that applicable in grit removal are not applicable and this settling is called as flocculant settling. The primary sedimentation tank generally removes 30 to 40% of the total BOD and 50 to 70% of suspended solids from the raw sewage. The flow through velocity of 1 cm/sec at average flow is used for design with detention period in the range of 90 to 150 minutes at average flow rate. This horizontal velocity will be generally effective for removal of organic suspended solids of size above 0.1 mm. Effluent weirs are provided at the effluent end of the rectangular tanks, and around the periphery in the circular tanks. Weir loading less than 185 m^3/m.d is used for designing effluent weir length (125 to 500 m^3/m.d). Where primary treatment follows secondary treatment higher weir loading rates can be used. The sludge collection hopper is provided near the centre in circular tank and near the influent end in rectangular tanks. A baffle is provided ahead of the effluent weir for removal of floating matter. This scum formed on the surface is periodically removed from the tank mechanically or manually.

11.1 Analysis of Flocculant Settling

Particles in relatively dilute concentration with smaller size sometimes will not act as discrete particles (as the grit particles behave in grit chamber) but these particles will coalesce during sedimentation. As flocculation occurs, the size of the particle increases and it settles faster. The magnitude of flocculation will depend upon the opportunity for contact between the particles, which depends upon overflow rate, temporal mean velocity gradient in the system (representing mixing) and concentration and size of the particles. Although, settling rate of particle is independent of depth of basin, the basin depth will decide liquid detention time in the tank and sufficient depth should be provided for settling to separate it from sludge settled zone. The effect of these variables on settling can only be determined by sedimentation tests, and classical laws of sedimentation are not applicable, due to change in characteristics of the particle during settling. Settling column is used to determine the settling characteristics of the suspension of flocculant particles. A column with diameter of 15 cm and height of 3.0 m can give satisfactory results, with 5 to 6 ports provided over the height for sampling. The height of the tank should be ideally equal to side water depth of the settling tank for proper results.

The solution containing suspended solids should be added in the column in such a way that uniform distribution of solid particles occur from top to bottom. Settling should takes place under quiescent conditions. It is important to maintain uniform temperature throughout the experimental column to avoid convection currents. At various time intervals, samples are withdrawn from the ports and analyzed for suspended solids. Percentage removal of solids is calculated for each sample analyzed and is plotted as a number (%) against time and depth. The curve of equal percentage removal is drawn between the plotted points.

The efficiency of the sedimentation tank, with respect to suspended solids and BOD removal, is affected by the following:

- Eddy currents formed by the inertia of incoming fluid,
- Wind induced turbulence created at the water surface of the uncovered tanks,
- Thermal convection currents,
- Cold or warm water causing the formation of density currents that moves along the bottom of the basin, and
- Thermal stratification in hot climates.

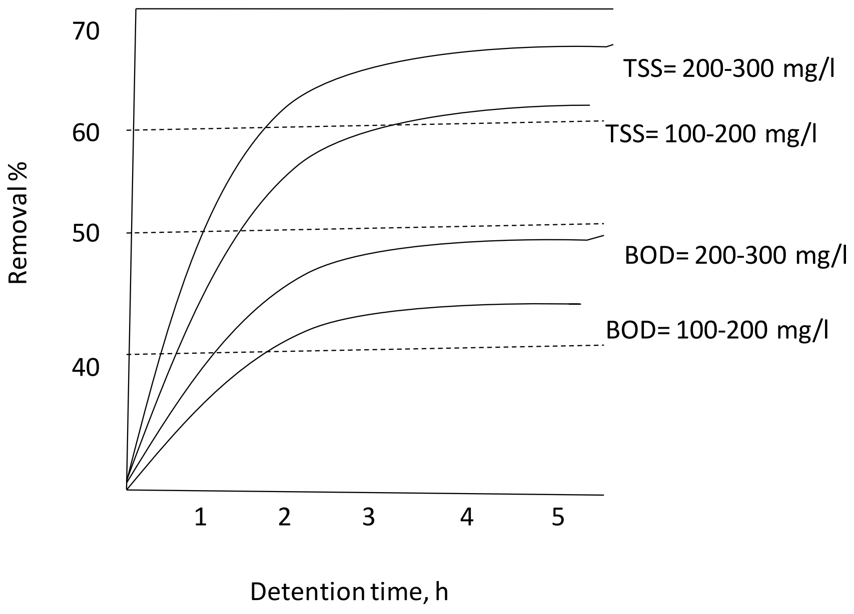

Figure 11.1 Performance of PST

Because of the above reasons the removal efficiency of the tank and detention time has correlation R = t/(a+b.t), where ‘a’ and ‘b’ are empirical constants, ‘R’ is expected removal efficiency, and ‘t’ is nominal detention time.

Table 11.1 Typical values for a and b.

Item	a	b
BOD	0.018	0.020
TSS	0.0075	0.014

To account for the non optimum conditions encountered in the field, due to continuously wastewater coming in and going out of the sedimentation tank, due to ripples formed on the surface of the water because of wind action, etc., the settling velocity (overflow rate) obtained from the column studies are often multiplied by a factor of 0.65 to 0.85, and the detention time is multiplied by a factor of 1.25 to 1.50. This will give adequate treatment efficiency in the field conditions as obtained under laboratory test.

Example: 1

The settling test was performed in the settling column of height 2.5 m. Four numbers of ports were provided to the column at the height of 0.5 m from bottom. Samples were collected from these ports at every 30 min and the results obtained are plotted in the Figure 16.1. Determine the overall removal of solids after 1.0 h of settling.

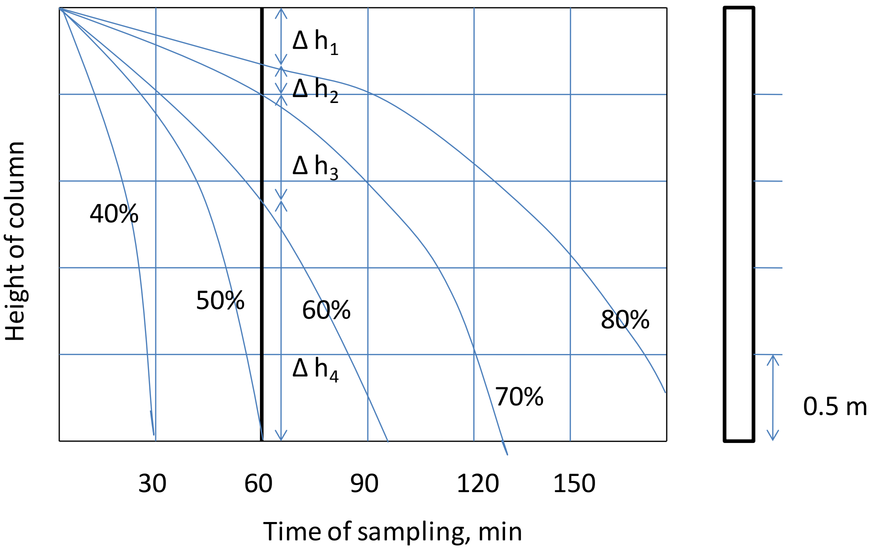

Figure 11.2. Results of the settling column study

Solution

$$\text{Percentage removal} = \frac{\Delta h_1}{h_5} x \frac{(R_1 + R_2)}{2} + \frac{\Delta h_2}{h_5} x \frac{(R_2 + R_3)}{2} + \frac{\Delta h_3}{h_5} x \frac{(R_3 + R_4)}{2} + \frac{\Delta h_4}{h_5} x \frac{(R_4 + R_5)}{2}$$

For curve shown in the Figure 16.1, the computation will be

$\frac{\Delta h_1}{h_5} x \frac{(R_1 + R_2)}{2} = 0.34(100+80)/(2.5 \text{ x } 2) = 12.24\%$

$\frac{\Delta h_2}{h_5} x \frac{(R_2 + R_3)}{2} = 0.16 (80 + 70)/(2.5 \text{ x } 2) = 4.8\%$

$\frac{\Delta h_3}{h_5} x \frac{(R_3 + R_4)}{2} = 0.66 (70 + 60)/(2.5 \text{ x } 2) = 17.16\%$

$\frac{\Delta h_4}{h_5} x \frac{(R_4 + R_5)}{2} = 1.34 (60 + 50)/(2.5 \text{ x } 2) = 29.48\%$

Therefore, total removal under quiescent settling condition is 63.68%. To achieve this removal the detention time recommended in settling tank is 1 x 1.5 = 1.5 h.

11.2 Recommendation for Design of Primary Sedimentation Tank

Primary sedimentation tanks can be circular or rectangular tanks (Figure 16.2) designed using average dry weather flow and checked for peak flow condition. The numbers of tanks are determined by limitation of tank size. Two tanks in parallel are normally used to facilitate maintenance of any tank. The diameter of circular tank may range from 3 to 60 m (up to 45 m typical) and it is governed by structural requirements of the trusses which supports scrapper in case of mechanically cleaned tank. Rectangular tank with length 90 m are in use, but usually length more than 40 m is not preferred. Width of the tank is governed by the size of the scrappers available for mechanically cleaned tank. The depth of mechanically cleaned tank should be as shallow as possible, with minimum 2.15 m. The average depth of the tank used in practice is about 3.5 m. In addition, 0.25 m for sludge zone and 0.3 to 0.5 m free board is provided. The floor of the tank is provided with slope 6 to 16 % (8 to 12 % typical) for circular tank and 2 to 8% for rectangular tanks. The scrappers are attached to rotating arms in case of circular tanks and to endless chain in case of rectangular tanks. These scrappers collect the solids in a central sump and the solids are withdrawn regularly in circular tanks. In rectangular tanks, the solids are collected in the sludge hoppers at the influent end, and are withdrawn at fixed time intervals. The scrapper velocity of 0.6 to 1.2 m/min (0.9 m/min typical) is used in rectangular tank and flight speed of 0.02 to 0.05 rpm (0.03 typical) is used in circular tank.

Inlets for both rectangular and circular tanks are to be designed to distribute the flow equally across the cross section. Scum removal arrangement is provided ahead of the effluent weir in all the PST. The surface overflow rate of 40 $m^3/m^2.d$ (in the range 35 to 50 $m^3/m^2.d$) is used for design at average flow. At peak flow the surface overflow rate of 80 to 120 $m^3/m^2.d$ could be used when this PST is followed by secondary treatment. Lower surface settling rates are used when waste activated sludge is also settled in the PST along with primary solids. In this case the surface overflow rate of 24 to 32 $m^3/m^2.d$ and 48 to 60 $m^3/m^2.d$ are used for average and peak flow conditions, respectively. The weir loading rate less than 185 $m^3/m.d$ is used for designing effluent weir length (in the range 125 to 500 $m^3/m.d$). Weir loading rate up to 300 $m^3/m.d$ is acceptable under peak flow condition. Higher weir loading can be acceptable when primary treatment is followed by secondary treatment. As such the weir loading rate has very less impact on the overall performance of sewage treatment plant when secondary treatment is provided after primary treatment. The detention time in PST could be as low as 1 h to maximum of 2.5 h. Providing detention time of 1.5 to 2.5 h at average flow is a common practice.

To avoid resuspension (scouring) of settled particles, horizontal velocities through the PST should be kept sufficiently low. Following equation by Camp can be used to calculate the critical velocity, Vc, which is the horizontal velocity that will just produce score (m/sec).

$$Vc = \sqrt{\left[\frac{8\beta}{f} g(S-1)D\right]}$$

Where, β = constant

= 0.04 for unigranular sand

= 0.06 for non-uniform sticky material

f = Darcy –Weisbach friction factor = 0.02 to 0.03

g = Gravity acceleration,

S = Specific gravity of the particle to be removed (1.2 to 1.6)

D = Diameter of the particle, m

For organic particle with size of 0.1 mm and specific gravity of 1.25 this velocity will be about 0.063 m/sec.

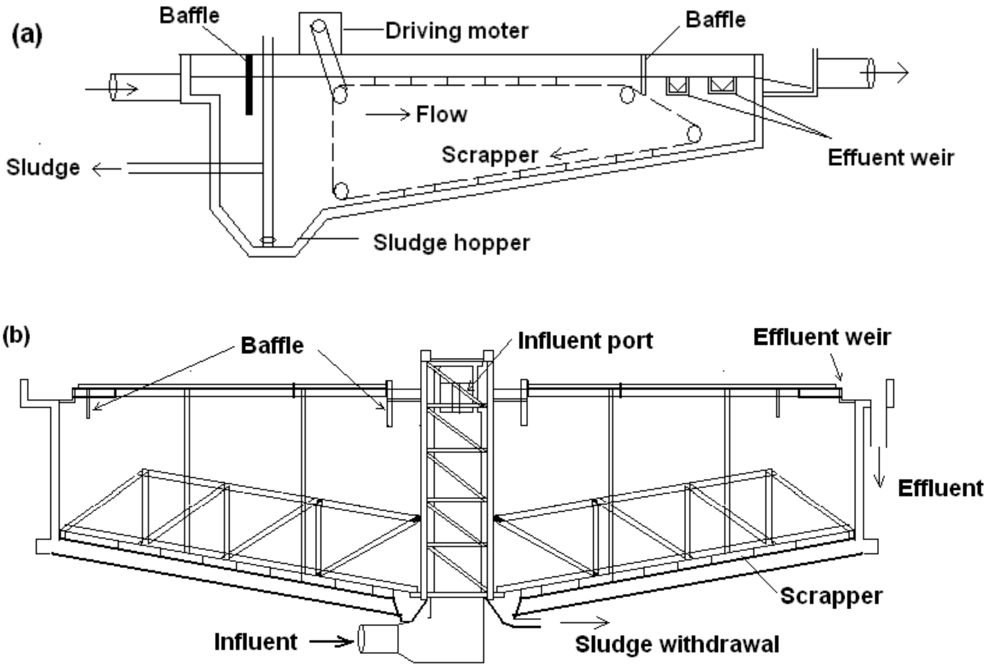

Figure 11.3 (a) Rectangular and (b) Circular primary sedimentation tank

Table 11.2 Typically design information for P S T

Parameter	**Range**	**Typical**
Detention time(h)	1.5- 2.5	2.0
Overflow rate $m^3/m^2.d$ Average flow Peak flow	 30 – 50 80 – 120	 40 100
Weir loading, $m^3/m.d$	125 – 500	250
For Rectangular Tank:		
Depth, m	3 – 4.9	3 - 4
Length, m	15 – 90	24 – 40
Width, m	3 – 24	5 – 10
Scupper velocity, m/min	0.6 – 1.2	0.9
Circular Tank:		
Depth, m	3 – 4.9	3-4
Diameter	3 – 60	12 – 45
Bottom slope	1/16 – 1/6	1/12
Flight speed, r/min	0.02 – 0.05	0.03

In generally weir loading rates have very little effect on the efficiency of primary sedimentation tanks.

Example 2

Design of Primary Sedimentation basin

The average flow rate at a small sewage treatment plant is 20000 m^3/d. The observed peak flow rate is 50000 m^3/d. Design rectangular primary clarifier with a channel width of 6 m. Use minimum two clarifiers. Calculate the scour velocity to determine if settled material will become resuspended. Estimate the BOD and TSS removal at average and peak flow. Adopt an overflow rate of 40 m^3/m^2.day at average flow and side water depth of 4 m.

Solution:

1) Assume surface settling rate = 40 m^3/m^2.d

Therefore, the surface area of the tank = Q/SOR = 20000 / 40 = 500 m^2

2) length of tank (L) = A/W = 500/ (2*6) = 41.7 (42 m) (For two tanks)
3) Detention time and overflow rate at average flow

   Tank Volume = 4* 2 (42*6) = 2016 m^3

   Overflow rate = Q/A = 20000/2(6*42) = 39.7 m^3/m^2.d

   Detention time = Vol/Q = (2016*24)/20000 = 2.42 h
4) Detention time and overflow rate at peak flow

   Overflow rate = Q/A = 50000/2(6*42) = 99.2 m^3/m^2.d

   Detention time = Vol/Q = (2016*24)/50000 = 0.97 h

   The scour velocity is

$$VH = \sqrt{\frac{8K(S-1).g.d}{f}} = \sqrt{\frac{8*0.05\ (1.25-1)*9.81*100*10^{-6}}{0.025}} = 0.063 \text{ m/sec}$$

By considering d = 100 µm

Horizontal velocity should be checked for peak flow

Horizontal velocity for peak flow = Q/A = 50000/(2*6*4*24*3600) = 0.012 m/s

Check for Weir loading rate = Flow/length of weir = 20000/(2*6) = 1666 m^3/m.d

Estimate BOD and TSS removal rate:

BOD removal rate R = t/(a+b.t) = 2.42/(0.018+0.02*2.42) = 36%

TSS removal rate R = t/(a+b.t) = 2.42/(0.0075+0.014*2.42) = 58%

At peak flow

BOD removal rate R = t/(a+b.t) = 2.42/(0.018+0.02*0.97) = 26%

TSS removal rate R = t/(a+b.t) = 0.97/(0.0075+0.014*0.97) = 46%

Example 3: Solution for 10000 m^3/d avg flow & 25000 m^3/d peak flow S.W.D =3.5m, width of the channel should be 6.0m

a) surface area of the tank = Q/SOR = 10000 / 40 = 250 m^2
b) length of tank (L) = A/W = 250/ 6 = 41.66 m^2

Provide two tank L = 20.83 m

Tank volume = 20.83*6* 3.5 = 437.5 m^3

Detention time = Vol/Q = 437.5/(10000/2) = 2.1 m ok (1.5 to 2.5)

The scour velocity is

$$VH = \sqrt{\frac{8K(S-1).g.d}{f}} = \sqrt{\frac{8*0.05\ (1.25-1)*9.81*100*10^{-6}}{0.025}} = 0.063 \text{ m/sec}$$

Horizontal velocity for peak flow = Q/A = 25000/(2*6*3.5) = 595.24 m/d = 0.0069 m/sec < 0.063 m/sec, Hence O.K.

TSS removal rate R = t/(a+b.t) = 2.1/(0.0075+0.014*2.1) = 56.9%

At peak flow = 437.5/12500 = 0.84 h

TSS removal = 0.84/0.0075+0.014*0.84 = 43.61%

Example: 4

Design the primary sedimentation tank to treat wastewater with average flow rate of 10 MLD and peak flow of 22.5 MLD.

Solution

Assume surface settling rate = 40 m^3/m^2.d

Therefore, the surface area of the tank = 10 x 10^6 / 40 x 10^3 = 250 m^2

Check for peak flow condition: The SOR at peak flow = 22.5 x 10^3 /250 = 90 m^3/m^2.d

This is less than the recommended value at peak flow.

Assume width = 6.0 m

Therefore theoretical length = 250/6 = 41.66 > 40 m

Hence, provide two tanks in parallel

Total length of each tank = 41.66/2 + 2 (inlet) + 2 (outlet) = 24.83 say 24.85 m

Now,

Flow rate x detention time = depth x surface area = volume of tank

Or Flow / Surface area = depth / detention time = Surface settling rate

Provide detention time of 1.5 h

Therefore, liquid depth required = 40 x 1.5 / 24 = 2.5 m

Therefore, flow through velocity = (0.116 m^3/sec) / (2 x 2.5 x 6)

= 0.0039 m/sec < 1 cm/sec hence O.K.

At peak flow, the flow through velocity = 22.5 x 10^3 /(2 x 6 x 2.5) = 750 m/d = 0.0087 m/sec.

(Horizontal velocity should be checked for non-scoring velocity i.e. less than 0.06 m/sec.)

Provide total depth = 2.5 + 0.5 (free board) + 0.25 (space for sludge) = 3.25 m

Weir loading rate = 10 x 10^3 / 12 = 833.33 m^3/m.day > 185 m^3/m.day

Length of weir required = 10 x 10^3 / 185 = 54.05 m

Hence, provide about 27.1 m of weir length for each tank. This can be provided by two effluent collection channel across the width at outlet end offering total 24.0 m and side weir of total 1.55 m on each side.

11.3 Plate settlers

This concept was first given by Allen Hazen in 1904. These devices are used in wastewater treatment for primary, secondary and tertiary sedimentation to enhance the settling characteristics of sedimentation basins. They consist of an array of plates usually provided at an angle between 45˚ to 60˚ to the horizontal to avoid solid accumulation in the plates. They are based on the principle that settling of particles depends on the settling area rather than the detention time. The suspension flows between the plates by gravity to the surface of the lower plates. As the solids build up on the lower plate to a point when gravitational force exceeds the shear resistance, the mass slides down. They are mostly used for primary and secondary clarification of municipal wastewater, phosphate removal as chemical floc and reducing suspended solids in effluent after ASP. Nominal spacing between plates is 50 mm with an inclined length of 1 to 2 m. Surface overflow rates used are in the range of 20-40 m^3/m^2.day.

Upflow clarifiers benefit from the forced collision between settling flocs and smaller flocs in rising water, but because the surface loading is the same as horizontal flow basin, they are, on an average less efficient, have a lower margin for variation and a significant risk of flushing the flocs through to the sludge blanket in case of overloads. So plate settlers can help in upgrading them. Plate settlers increase the effective surface area of the existing clarifiers and sedimentation basins at water treatment facilities. New tanks can be greatly reduced in size when designed to include plate settlers. This is because **suspended solids removal in gravity separators and clarifiers depends primarily on the surface area for settling** and the multiple parallel plates provide a large surface area in a small space. Plate settlers can reduce retention time, thus increasing the efficiency. The plate settlers are:

(1) used to add surface area to decrease overflow velocity,

(2) used to avoid hydraulic short circuiting, and

(3) capable of self cleaning when inclined to the horizontal.

One drawback is the growth of bacteria and foul odour resulting from the accumulation of solids. So the solids should be flushed periodically to avoid this nuisance.

Three types of plate settlers are designed based on the direction of liquid flow relative to direction of particle settlement

(1) Upflow or countercurrent (Fig 1a)

(2) Downflow or concurrent (Fig 1b)

(3) Cross current (Fig 1c).

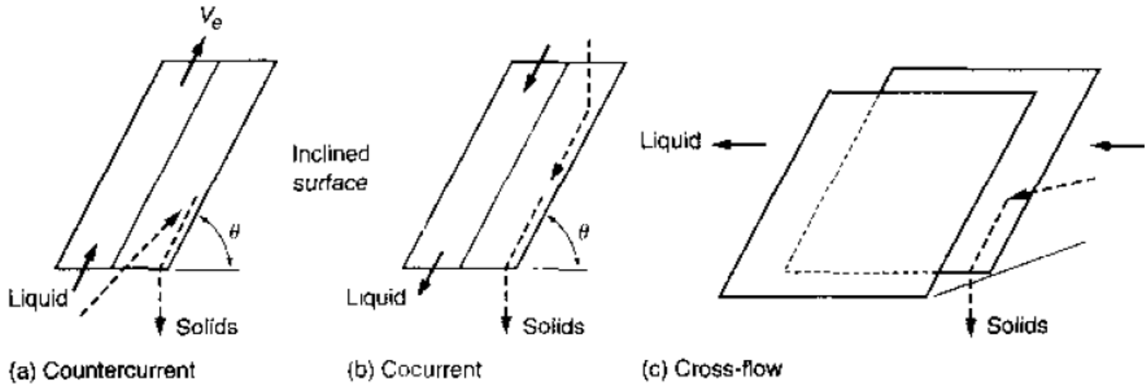

Fig. 11.4 Types of plate settler

(1) Upflow or counter current, - Here settled sludge slides down the plates while the water is flowing up. In countercurrent settling, time required for the particle to settle the vertical distance is given by

$$t = \frac{w}{v\cos\theta}$$

where, w – perpendicular distance between surfaces (m)
v – settling velocity (m/s)
θ – angle of inclination with the horizontal

The length of surface needed to provide this time, $L_p = \frac{w(v' - v\sin\theta)}{v\cos\theta}$

where, v' is the velocity of liquid between the surface.

All particles with settling velocity v or greater than v are removed if

$$v \geq \frac{v'w}{Lp\ cos\theta + W\ sin\theta}$$

(2) Downflow or concurrent settling - Here settled sludge slides down the plates while water flow is also down. The solids suspension is introduced above the inclined surface and the flow is down through the plates. The time for a particle to settle a vertical distance between the two surfaces is same as in case of concurrent settling.

Length of the surface needed, $L_p = \frac{w(v' + v\ sin\theta)}{v\ cos\theta}$

All particles with settling velocity v or greater than v are removed if

$$v \geq \frac{v'w}{Lp\ cos\theta - W\ sin\theta}$$

(3) Crosscurrent –In this case settled sludge slides down the plate and the water flows across the plates. The liquid is flowing in the horizontal direction and has no interaction with the vertical settling velocity. So

$$L_p = \frac{w\ v'}{v\ cos\theta}$$

And the condition for settling is

$$v \geq \frac{v'w}{Lp\ cos\theta}$$

11.4 Lamella Clarifier

There are a number of proprietary lamella clarifier designs. Inclined plates may be based on circular, hexagonal or rectangular tubes. Some possible design characteristics include:

- Tube or plate spacing of 50 mm
- Tube or plate length 1–2 m
- Plate pitches between 45° and 70° allow for self-cleaning, lower pitches require backwash
- Minimum plate pitch 7°

- Typical loading rates are 5 to 10 m/h.
- Retention time 60 to 120 min.

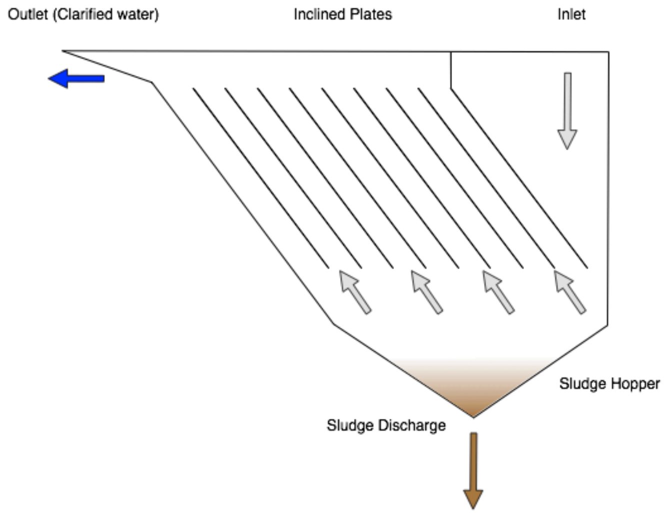

Figure 11.5 Lamella clarifier

Lamella clarifiers can handle a **maximum** feed water concentration of **10000 mg/L of grease** and **3000 mg/L of solids**. Expected separation efficiencies for a typical unit are as follows:

- 90-99% removal of free oils and greases under standard operation conditions.
- 20-40% removal of emulsified oils and greases with no chemical amendment.
- 50-99% removal with the addition of chemical agent(s).
- Treated water has a turbidity of around 1-2 NTU.

The surface loading rate (also known as surface overflow rate or surface settling rate) for a lamella clarifier falls between 10–25 m/h. For these settling rates, the retention time in the clarifier is low, at around 20 minutes or less, with operating capacities tending to range from 1–3 m^3/hour/m^2 (of projected area).

Design details

- Rise rate: Rise rates can be between 0.8 and 4.88 m/h from different sources.
- Plate loading: Loadings on plates should be limited to 2.9 m/h to ensure laminar flow is maintained between plates.
- Plate angle: The general consensus is that plates should be inclined at a 50-70° angle from the horizontal to allow for self-cleaning. This results in the projected plate area

of the lamella clarifier taking up approximately 50% of the space of a conventional clarifier.

- Plate spacing: Typical spacing between plates is 50 mm, though plates can be spaced in the range of 50–80 mm apart, given that the particles > 50 mm in size have been removed in pre-treatment stages.
- Plate length: Depending on the scale of the system, total plate lengths can vary, however, the plate length should allow for the plates 125 mm top water level, with 1.5 m of space left below the plates at the bottom of the clarifier for collection of sludge. Most plates have a length of 1–2 m.
- Plate materials: Plates should be made of stainless steel, with the exception of situations in which the system has been dosed with chlorine to prevent algal growth. In these circumstances, the plates may be plastic or plastic coated.
- Feed point: Feed should be introduced at least 20% below the base of the plate to prevent disturbance of the settling zones at the base of the plates.

Example 5:

Design a plate settler for a secondary treatment of wastewater having flow rate of 40 MLD.

Solution

Assuming a SOR of 20 m^3/m^2.day, area of plate settler = $\frac{40000}{20}$ = 2000 m^2

Let the dimension of a plate be 1.3 m x 3.0 m and it is placed at an inclined angle of 55° to the horizontal.

Area of each plate = 1.3 x 3 x cos 55° = 2.237 m^2

Number of plates required = $\frac{2000}{2.237}$ = 894.05 (895 say)

So a total of 895 plates having dimension of 1.3 m x 3 m inclined at 55° to the horizontal are required.

11.5 Secondary Sedimentation Tank

Table 11.3 Design parameters for SST

Parameter	Overflow rate, $m^3/m^2.d$		Solid loading rate, $kg/m^2.d$		Depth, m	Detention time, h
	Average	Peak	Average	Peak		
SST for TF	15 - 25	40 - 50	70 - 120	190	2.5 – 3.5	1.5 – 2.0
SST for ASP	15 - 25	40 - 50	70 - 140	210	3.5 – 4.5	1.5 – 2.0
SST for extended aeration ASP	8 - 15	25 - 35	25 - 120	170	3.5 – 4.5	1.5 – 2.0

Weir loading rate less than 185 $m^3/m.d$ is used for design of SST.

Example 6: Design a SST for ASP to handle equalized wastewater flow of 1000 m^3/d. The MLSS in aeration tank is 3500 mg/L.

Solution:

Example 7: Design SST to treat effluent from ASP with following data.

Avg. flow = 50 MLD

MLSS conc. in influent = 3000 mg/L

Peak flow factor = 2.25

Solution:

Adopt surface loading rate = 20 $m^3/m^2.d$ at avg. flow

Surface area required = $50*10^6/(20*1000)$ = 2500 m^2

Check for surface loading at peak flow

Surface loading = $\frac{50*2.25*10^6}{2500*1000}$ = 45 $m^3/m^2.d$ (O.K. 40-50)

For solid loading of 80 $kg/m^2.d$ at avg. flow

Area required =$\frac{50*3000*10^6}{1000*80*1000}$ = 1875 m^2 < 2500 m^2 (hence O.K)

Area required for peak solid loading =$\frac{50*3000*10^6*2.25}{1000*80*1000*210}$ = 1607 m^2 < 2500 m^2, hence O.K

Provide diameter = $\sqrt{\frac{2500*4}{\pi}}$ = 56.4 m (It is better to provide two tanks).

Check for weir loading (for single tank) = $50*1000/\pi*57$ = 279.21 $m^3/m.d$ > 185 $m^3/m.d$

Length of weir required = 50*1000/180 = 277.77

Provide additional weir length in the form of launders projecting inside.

Depth say HRT = 2 hr. vol = Q*2 = 4166.6 m^3

Depth = 4166.6/2500 = 1.67 m Provide 2 m depth + 0.3 m Free board + 0.25 m sludge accumulation zone.

Questions

1. Describe flocculant settling.
2. What is the purpose of providing primary sedimentation tank in wastewater treatment? What is the expected BOD and SS removal is primary sedimentation tank?
3. What are the parameters which will govern performance of PSTs?
4. Describe design guidelines for primary sedimentation facilities.
5. Design circular and rectangular PST for treatment of 4 MLD of average sewage flow with peaking factor of 2.
6. Describe Lamella clarifier.
7. What are the advantages of plate settler over conventional clarifier.