Sanitary and Environmental Engineering

PART 2: WASTEWATER ENGINEERING

PART 2: WASTEWATER ENGINEERING

Lecture 7: Preliminary and Primary Treatment

Note:

a) The headwork of wastewater plants usually incorporates a flow measurement device as a Parshall flume and mechanical or physic-chemical system designed for removal of large floating solids, grit and perhaps grease (preliminary treatment systems).
b) Primary treatment has traditionally implied a sedimentation process intended to remove suspended organic solids. Chemicals are sometimes added in primary clarifiers to assist in removal of finely divided and colloidal solids or to precipitate.

1. **Low lift sewage pump station:**

2. **Screen**: A protective device used to remove large and coarse materials from the wastewater, which may damage equipment.

   a) Types: rack, mesh

   b) Openings: Coarse more than 50 mm, medium 25-50 mm, fine less than 25 mm.

   c) Flowing velocity through the openings: v_f= 0.6-1.2 m/sec

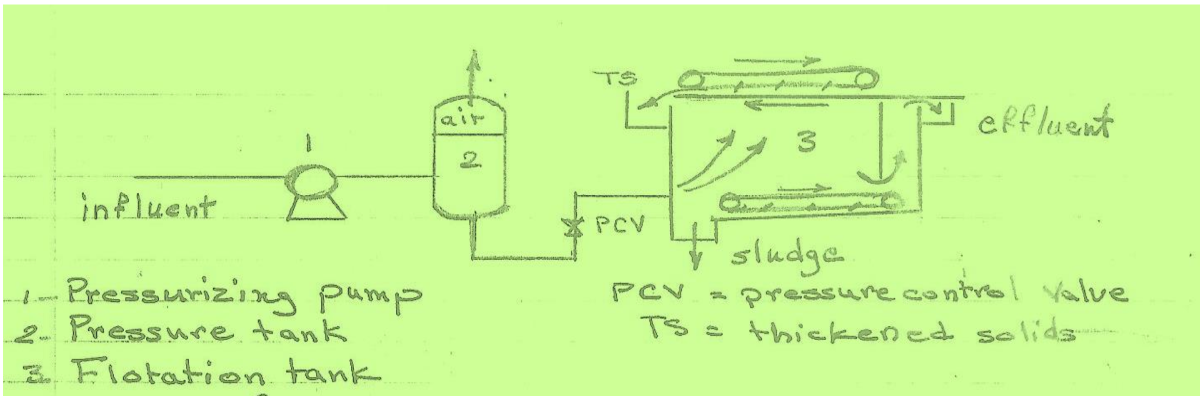
3. **Flotation or Skimming tank:** To separate solid and liquid particles (grease and oil) from the wastewater by the introduction of air bubbles. The particles are attached to the bubbles and by the buoyancy forces, the particles are raised to the water surface. The floating particles are removed by skimming.

   Types: Dissolved air flotation, Dispersed air flotation

Dissolved air flotation (DAF): Air bubbles are introduced by injection of air to the water under pressure. Air is dissolved under 250-450 kPa in the pressure tank, where the water is held for several minutes.

The components of this tank:

1-pressurizing pump 2-pressure tank 3-flotation tank



The performance of this system depends on:

$\frac{A}{S} = 1.3 \times S_a \times \frac{(f \times P - 1)}{C_i}$

Temperature °C	0	10	20	30
S_a mL/L	29.2	22.8	18.7	15.7

$\frac{A}{S}$: Air to solid ratio (mL of air/ mg solids)
S_a: Solubility of air depending on temperature (mL/L)
ρ_{air}= 1.3 mg /mL
f = Fraction of dissolved air at pressure (P) = 0.5
P = Pressure, atm ($P_{atm} = \frac{P_{kPa}+101.35}{101.35}$).
C_i = Concentration of suspended solids in the influent (mg/L)

Design criteria:
Detention time = 3-30 min
Flowing velocity = 50-250 mm/sec
$\frac{A}{S}$= 0.005-0.6 mL/mg
Surface loading rate = velocity to rise the suspended solids = 8-160 L/m^2.min ($SLR = \frac{Q}{A_S}$).
The quantities of float skimming = (3-7) % of incoming flow.

Dispersed air flotation: Air bobbles are formed by aeration at atmospheric pressure using revolving impellers or turbine aerators. The advantages of a dispersed-air flotation system are:

a) Compact size,
b) Lower capital cost, and
c) Capacities to remove relatively free oil and suspended solids.

The disadvantages of induced-air floatation:

a) Higher connected power requirements than the pressurized system,
b) Performance is dependent on strict hydraulic control, and
c) Less flocculation flexibility.

4. **Grit Chamber:** A sedimentation tank designed mainly for the removal of grits: sand, gravel, glass and other heavy solids from wastewater. The separation of inorganic and organic solids takes place due to the difference in the specific gravity of these particles. This parameter affects the settling velocity v_s and the scouring velocity v_h for these particles where they are used for design requirements.

As the flow in this tank is turbulent:

All particles are assumed to settle in according with Newton Law: $v_s = \sqrt{\frac{4g \times (G_S - 1) \times d}{3C_D}}$ & for sedimentation: $v_s = SOR = \frac{Q}{A_S} = \frac{Q}{W \times L}$

To be scour at velocity: $v_h = \sqrt{8\left(\frac{\beta}{f}\right) \times g \times (G_s - 1) \times d}$ & $v_h = \frac{Q}{A_C} = \frac{Q}{W \times H}$

v_h should be more than v_f (flowing velocity)

For design:

SOR = v_s for inorganic particles:

v_s for organic particles < v_f < v_s for inorganic particles

Types: Aerated grit chambers, Horizontal flow grit chambers.

Aerated grit chamber: The separation of different types of solids is done by producing a rolling flow similar to the spiral flow by using air. The velocity of the flow v_f is to be below v_s for inorganic particles and above v_s organic particles.

v_s for organic particles $<$ v_f $<$ v_s for inorganic particles

Design criteria:

1- Detention time= 2-4 min
2- Dimensions for a rectangular tank:
L = 8-20 m, W = 2-5 m, H = 2-7 m
W/H = 1:1 – 5:1
L/H = 3:1 – 5:1
3- Air flow rate = 0.015-0.5 m^3/min/ m length

Horizontal flow grit chamber: It is designed to provide sufficient time for inorganic particles to settle and the flowing velocity will carry out the organic particles. The velocities for design (v_s and v_h) are being controlled for the variation of the wastewater flow.
To control the velocities;
1- Using the proportional weir;
2- Using the parabolic cross section.

Design criteria:

1- Detention time= 30 -90 min
2- v_f = 0.2-0.4 m/sec
3- Dimensions:
L = 3 -25 m, H = 1-2 m
L/H less than 12
4- Quantity of grit = $2.5 \times 10^{-6} - 1.8 \times 10^{-4} \frac{m^3}{m^3} of\ wastewater$

<u>**NOTE:**</u> To assure removal of grit (inorganic matter), while permitting such organic matter as might settle to be re-suspended by scour, the necessary condition may be calculated as follow:
For particles of grit (inorganic matter), with diameter of 0.2 mm and specific gravity = 2.65,

$$v_s = \sqrt{\frac{4g \times (G_s - 1) \times d}{3C_D}} = \sqrt{\frac{4 \times 980 \times (2.65 - 1) \times 0.02}{3 \times 10}} = 2.1\ cm/sec$$

The scour velocity of inorganic particles is given by:

$$v_h = \sqrt{8\left(\frac{\beta}{f}\right) \times g \times (G_s - 1) \times d} = \sqrt{8\left(\frac{0.06}{0.03}\right) \times 980 \times (2.65 - 1) \times 0.02} = 23\ cm/sec$$

For particles of organic matter, with diameter of 0.2 mm and specific gravity = 1.1,

$$v_s = \sqrt{\frac{4g \times (G_s - 1) \times d}{3C_D}} = \sqrt{\frac{4 \times 980 \times (1.1 - 1) \times 0.02}{3 \times 10}} = 0.511\ cm/sec$$

The scour velocity of organic particles is given by:

$$v_h = \sqrt{8\left(\frac{\beta}{f}\right) \times g \times (G_s - 1) \times d} = \sqrt{8\left(\frac{0.06}{0.03}\right) \times 980 \times (1.1 - 1) \times 0.02} = 5.6\ cm/sec$$

Thus, if the basin is designed to have a surface overflow rate of 0.021 m/sec and a horizontal velocity greater than 0.056 m/sec and less than 0.23 m/sec will remove grit (inorganic material) without removing organic material. To assure that the grit is reasonable clean, the horizontal velocity is generally close to the scour velocity of the grit.

5. **Primary sedimentation tank**: To remove settleable solids mainly inorganic. It is designed to remove 50 -70% inorganic particles and 25-40% organic particles. Removal curves for suspended solids (SS) indicating inorganic, and BOD indicating organic particles with SOR of the tank are used for design, (Fig. 23-1 page 470 and Fig. 23-2 page 471) or the readings from these curves are given in the table below.

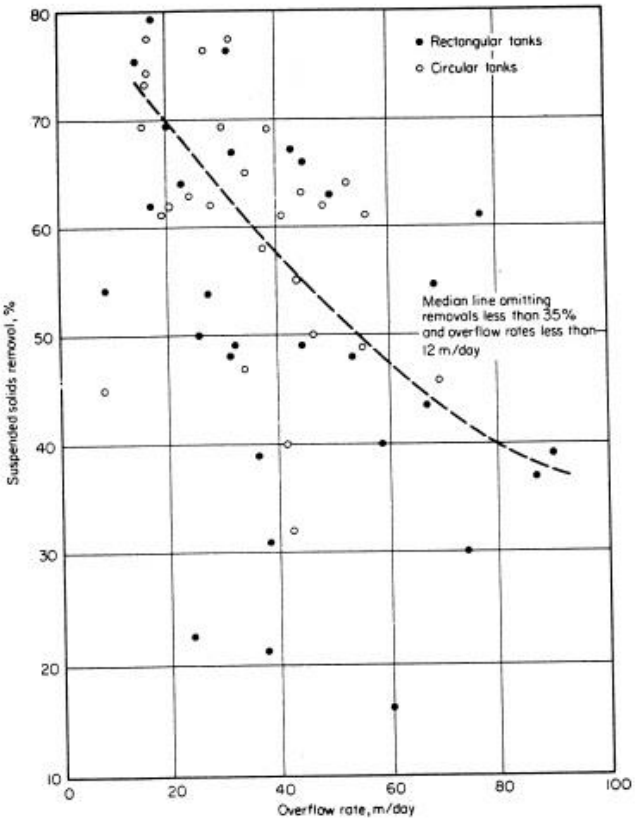


Fig. 23-1: Suspended solids removal in primary clarifiers.

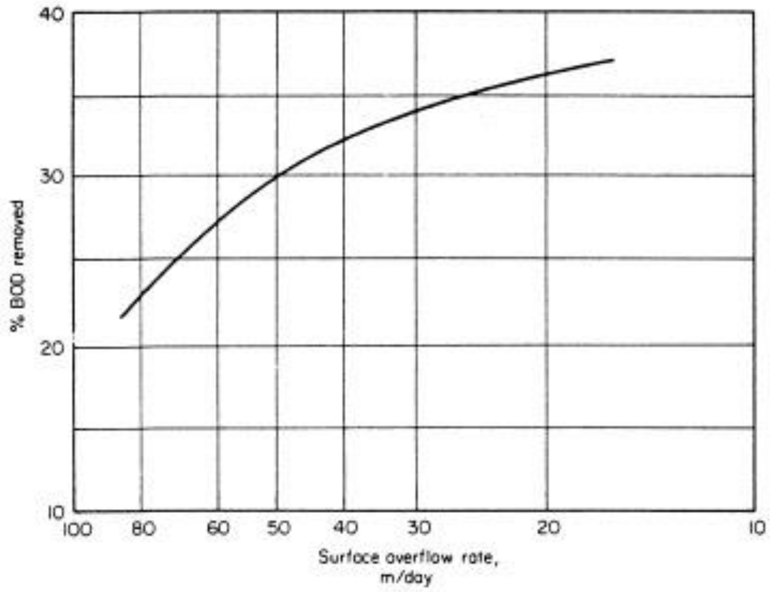


Fig. 23-2: BOD removal in primary clarifiers.

SOR m/d	20	30	40	50	60	70	80
% SS removal	70	65	58	53	48	45	40
% BOD removal	36	34	32.8	30	27.5	25	22.5

Design criteria:

1- Detention time = 1 -4 hr

2- SOR = Average flow 30-50 m/d & maximum flow 80 – 120 m/d

3- v_f = 0.6-3.6 m/min

4- Weir loading rate = 125-600 m^3/m/d

5- Dimensions:

Rectangular L = 15-100 m, H = 3 -5 m, W = 3 -30m

Circular D less than 60m

6- Scum removed average about = $7.5 \times 10^{-6} \frac{m^3}{m^3} of\ wastewater\ flow$

Solved problems

Problem 1: A flotation tank is used for thickening suspended solids (oil) of 3000 mg/L, knowing that: $\frac{A}{S}$= 0.008 mL/mg, temperature =20°C, surface loading rate = 8 L/m^2.min, Q= 400 m^3/d. Find: 1-required pressure P (kPa) inside pressure tank, 2- Surface area of the flotation tank (m^2) & 3) The quantities of float skimming if (7)% of incoming flow?
?
Solution:
1) From table at T = 20°C, air solubility S_a = 18.7 mL/L

$\frac{A}{S} = 1.3 \times S_a \times \frac{(f \times P - 1)}{C_i} \Rightarrow 0.008 = 1.3 \times 18.7 \times \frac{(0.5 \times P - 1)}{3000} \Rightarrow P = 3.98\ atm$

$\therefore P = 3.98\ atm = \dfrac{P_{kPa} + 101.35}{101.35} \Rightarrow P = 302\ kPa$

2) $A_s = \frac{Q}{Surface\ Loading} = \frac{400 \times 10^3\ L/day}{8 \times 24 \times 60\ L/day} = 34.7\ m^2$

3) $\frac{kg}{day} = 3000 \frac{mg}{L} \times 10^{-3} \times 400 \frac{m^3}{day} \times 0.07 = 84\ kg/day$

Problem 2: Design a horizontal flow girt chamber (rectangular) of a parabolic section. Knowing that Q_{max} = 18,000 m^3/d, Qavg = 15,000 m^3/d ,Q_{min} = 10,000 m^3/d, Gs inorganic particles = 2.65, Gs organic particles = 1.1, C_D =10, β/f = 2, detention time = 1 min, particles to be removed = 0.2 mm in diameter?
Solution:
For inorganic particles, Gs = 2.65:

$$v_s = \sqrt{\frac{4g \times (G_s - 1) \times d_s}{3C_D}} = \sqrt{\frac{4 \times 980 \times (2.65 - 1) \times 0.02}{3 \times 10}} = 2.076\ \approx 2.1\ cm/sec$$

$$v_s\ for\ inorganic\ particles = SOR = \frac{Q}{A_S}$$

Surface area of grit chamber:

$A_s = \frac{18000}{0.021 \times 24 \times 60 \times 60} = 9.921\ m^2 = L \times W$ (1)

$$v_h = \sqrt{8\left(\frac{\beta}{f}\right) \times g \times (G_s - 1) \times d_s} = \sqrt{8\left(\frac{0.06}{0.03}\right) \times 980 \times (2.65 - 1) \times 0.02} = 23\ cm/sec$$

For organic particles, Gs = 1.1:

$$v_h = \sqrt{8\left(\frac{\beta}{f}\right) \times g \times (G_s - 1) \times d_s} = \sqrt{8\left(\frac{0.06}{0.03}\right) \times 980 \times (1.1 - 1) \times 0.02} = 5.6\ cm/sec$$

For design Ac:

$$v_{h\ organic} < v_{h\ design} < v_{h\ inorganic}$$

Assume $v_{h\ design} = 0.2\ m/sec$

$\therefore A_c = \frac{Q}{v_h} = \frac{18000}{0.2 \times 24 \times 60 \times 60} = 1.042\ m^2 = H \times W$ (2)

$V = Q \times t = \frac{18000 \times 1\ min}{24 \times 60} = 12.5\ m^3 = L \times W \times H$ (3)

Solving eq. 1, 2, & 3 and find: $L = 12\ m$, $W = 0.827\ m$, & $H = 1.26\ m$

Assume use area of parabolic section = $\frac{2}{3} WZ$, Where:

W: Width at the design level.

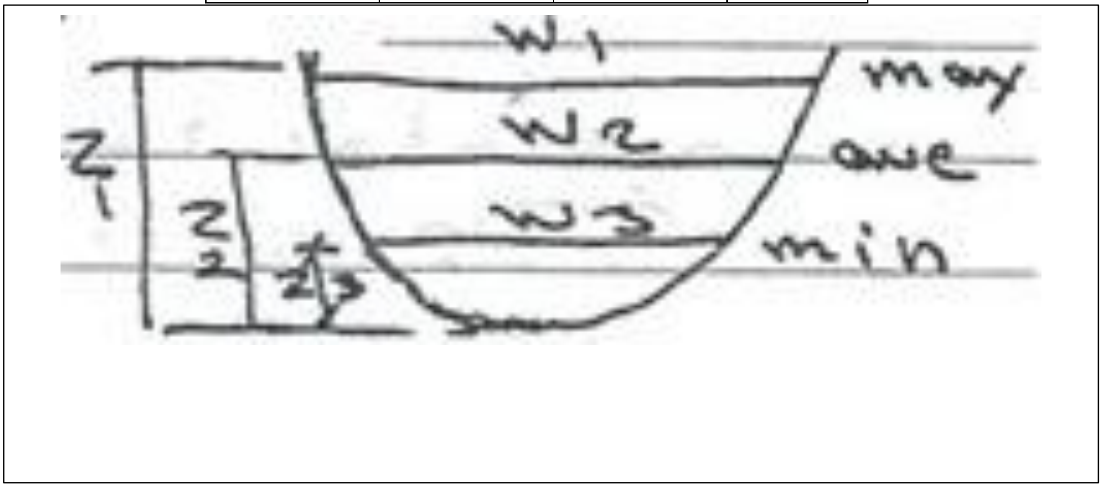
Z: Height at the design level.

$$Z = C \times W^2$$

So, for A_C, $A_C = \frac{2}{3} WZ \rightarrow 1.042 = \frac{2}{3} \times 0.827 \times Z \rightarrow Z = 1.889\ m$

$$Z = C \times W^2 \rightarrow 1.889 = C \times 0.827^2 \rightarrow C = 2.763$$

Q (m^3/day)	A_C (m^2)	W (m)	Z (m)
18000	1.042	0.827	1.889
15000	0.868	0.78	1.68
10000	0.579	0.68	1.289



Problem 3: Design a primary sedimentation tank for 60% SS removal. The influent flow is 10,000 m^3/d, and assume the detention time = 2hr? Also find the SS settling and effluent sludge if the influent SS concentration 2000 mg/L?

Solution:

From Fig. 23-1 or Table for 60% SS removal, SOR = 37 m/day and from Fig. 23-2 or Table 33% BOD removal.

$$SOR = \frac{Q}{A_s} \rightarrow A_s = \frac{Q}{SOR} = \frac{10000}{37} = 270\ m^2$$

If circular tank: $A = \frac{\pi}{4}D^2 \rightarrow 270 = \frac{\pi}{4}D^2 \rightarrow D = 18.5\ m$

$$V = Q \times t = A_s \times H \rightarrow \frac{10000}{24} \times 2\ hr = 270 \times H \rightarrow H = 3.1\ m$$

Weir loading rate, $WLR = \frac{Q}{Weir\ length} = \frac{10000}{\pi \times 18.5} = 172\ m^3/(m.day)$ O.K

If rectangular tank: Assume W = 10 m, so, $A = L \times W \rightarrow 270 = L \times 10 \rightarrow L = 27\ m$

Weir loading rate, $WLR = \frac{Q}{Weir\ length} = \frac{10000}{10} = 1000\ m^3/(m.day)$ not O.K

Assume weir loading rate = 600 m^3/(m.day) & weir length = 17 m

The influent sewage SS, $\frac{kg}{day} = 2000 \times 10^{-3} \times 10000 = 20000\ kg/day$

The influent SS settling sludge, $\frac{kg}{day} = 2000 \times 10^{-3} \times 10000 \times 0.6 = 12000\ kg/day$

The effluent SS, $\frac{kg}{day} = 2000 \times 10^{-3} \times 10000 \times 0.4 = 8000\ kg/day$

Problem 4: A raw wastewater containing 250 mg/L SS and 200 mg/L BOD passes through a clarifier with a surface area of 500 m^2. The flow ranges from 10000 m^3/day to 30000 m^3/day. Estimate the effluent BOD and SS at maximum and minimum flow, and the maximum and minimum rate of sludge production? Assume the sludge is 95 percent water.

Problem 5: Design a primary clarifier system for a community with population of 50000 persons. Size the clarifiers so that the SOR will be not more than 40 m/day at peak flow with one unit out of service and not more than 25 m/day at average flow? The minimum retention time is to be 1 hour and maximum weir loading rate 370 m^3/m.day. Also estimate the quantity of sludge which must be removed? If the sludge pumping cycle is 15 min/hour at maximum, what flow must the pump be sized to handle?

Problem 6: Design a primary clarifier system for a community with population of 50000 persons with a water supply demand 180 L/capita.day, and assuming that 80% of water supplied to the community is converted into sewage. Size the clarifiers so that the SOR will be not more than 40 m/day at peak flow (case 1) and not more than 25 m/day at average flow (case 2) with one unit out of service? The minimum retention time is to be 1 hour and maximum weir loading rate 370 m^3/m.day. Also, find the percent removal SS and BOD for each SOR?

SOR m/d	20	30	40	50	60	70	80
% SS removal	70	65	58	53	48	45	40
% BOD removal	36	34	32.8	30	27.5	25	22.5

Solution:

Average sewage flow: $Q_{Avg} = 0.8 \times 180 \times 50000 = 7200000 \frac{L}{day} = 7200\ m^3/day$

Peak sewage flow: $Q_{Peak} = 0.8 \times 1.8 \times 180 \times 50000 = 12960000\ \frac{L}{day} = 12960\ m^3/day$

Case 1: SOR = 40 m/day at peak flow:

$SOR = \frac{Q}{A_s} \rightarrow A_s = \frac{12960}{40} = 324\ m^2 \rightarrow D = 20.32\ m$ use D = 20 m & $Q = \frac{V}{t} \rightarrow V = 12960 \times \frac{1}{24} = 540\ m^3, H = \frac{V}{A_s} = \frac{540}{324} = 1.667\ m$

$WLR = \frac{Q}{L} = \frac{12960}{\pi \times 20} = 206.369\ \frac{m^3}{m.day} < 370\ \frac{m^3}{m.day}$ O.K

From table at SOR = 40 m/day: SS% removal = 58% and BOD% removal = 32.8%

Case 2: SOR = 25 m/day at average flow:

$SOR = \frac{Q}{A_s} \rightarrow A_s = \frac{7200}{25} = 288\ m^2 \rightarrow D = 19.15\ m$ use D= 19 m & $Q = \frac{V}{t} \rightarrow V = 7200 \times \frac{1}{24} = 300\ m^3$, $H = \frac{V}{A_s} = \frac{300}{288} = 1.041\ m$

$WLR = \frac{Q}{L} = \frac{7200}{\pi \times 19} = 120.683\ \frac{m^3}{m.day} < 370\ \frac{m^3}{m.day}$ O.K

From table at SOR = 25 m/day: SS% removal = 67.5% and BOD% removal = 35%

Population equivalent or unit per capita loading, (PE), in waste-water treatment is the number expressing the ratio of the sum of the pollution load produced during 24 hours by industrial facilities and services to the individual pollution load in household sewage produced by one person in the same time.

The population equivalent (P.E.) of a waste may be determined by divided the total mass per day by the per mass loadings. Population equivalent has been used as a technique for determining industrial waste treatment costs. PE may be determined on the basis of flow, BOD_5, COD, TSS, P, N, etc.

Example: An industrial waste of 1000 m^3/day and having a BOD_5 of 500 mg/L, calculate the population equivalent in terms of BOD_5 if the domestic BOD loading = 95 gm/(cap.day)?

Solution:

$$PE = \frac{0.5 \times 10^3 \ \frac{gm}{m^3} \times 1000 \ m^3/day}{95 \ gm/(capita.day)} = 5263 \ capita$$

Example: A waste with a BOD of 300 mg/L and a flow of 1000 m^3/day L, calculate the population equivalent in terms of BOD_5 if the domestic BOD loading = 80 gm/(cap.day)?

Solution:

$$PE = \frac{0.3 \times 10^3 \ \frac{gm}{m^3} \times 1000 \ m^3/day}{80 \ gm/(capita.day)} = 3750 \ capita$$