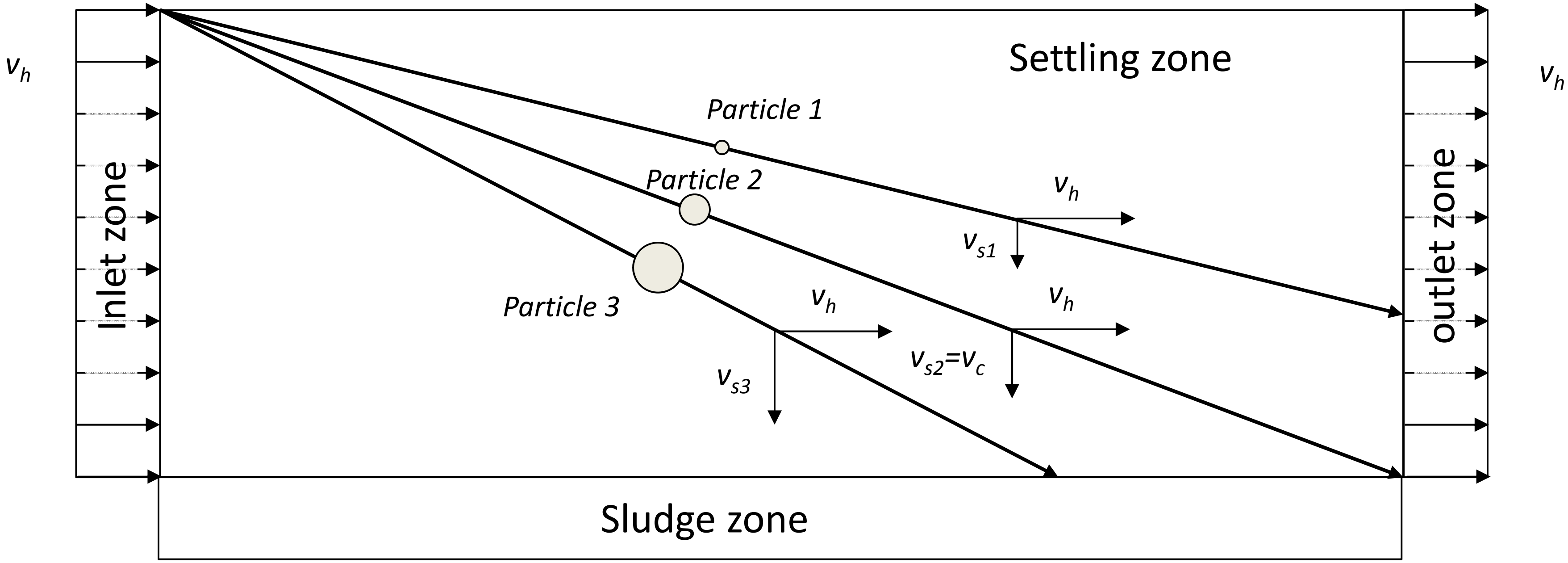
Physical unit processes II

Removal of particles in sedimentation basins

Assume a rectangular sedimentation basin:



particle 1: $v_{s1} < v_c$ → partial removal

particle 2: $v_{s2} = v_c$ → 100% removal

particle 3: $v_{s3} > v_c$ → 100% removal

Removal of particles in sedimentation basins

- Designing sedimentation basins
  - Select a particle with a terminal velocity v_c and design the basin such that the particle can just be 100% removed
    - particles with terminal velocity greater than v_c will be 100% removed
    - particles with terminal velocity smaller than v_c will be partially removed

Removal of particles in sedimentation basins

From the diagram in the previous slide,

(time for water to flow through the settling zone) [1]

= (settling zone length, L) / (horizontal velocity, v_h)

(time for particle with settling vel. of v_c entering at the top, to settle) [2]

= (settling zone height, H) / (settling velocity, v_c)

Equating [1] and [2], $\frac{L}{v_h} = \frac{H}{v_c}$

$$\Rightarrow \boxed{v_c = \frac{Q}{A}}$$

v_c = ***overflow rate*** *(m/s)*

A = surface area of settling zone (m^2)

Removal of particles in sedimentation basins

- Removal rate for particles with settling velocity less than v_c

$$X_r = \frac{v_p}{v_c}$$

X_r = fraction removed for particles with settling velocity v_p

- Removal rate for particles with a range of different settling

$$Fraction\ removed = (1 - x_c) + \int_0^{x_c} \frac{v_p(x)}{v_c} dx$$

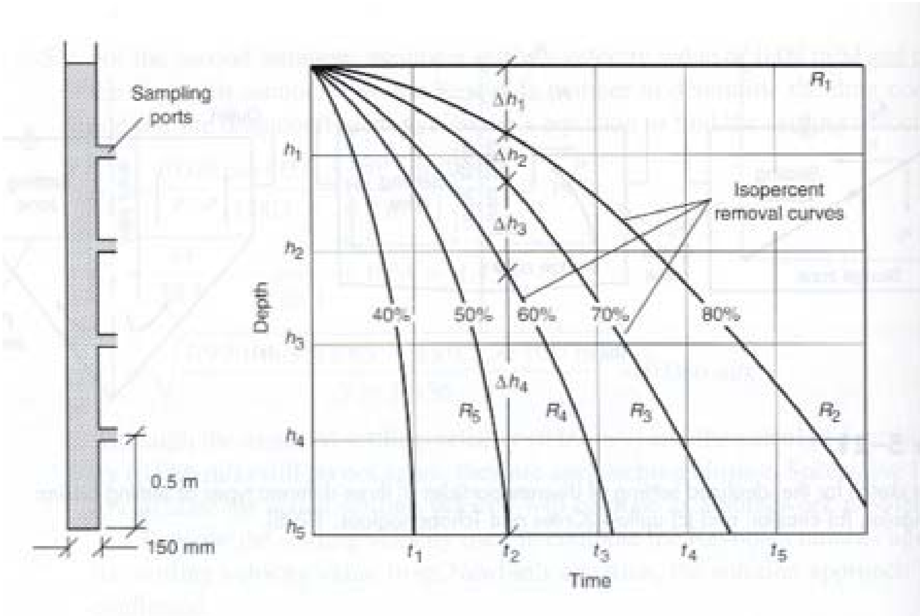
x = fraction of particles having terminal velocity $v_p(x)$

x_c = fraction of particles with $v_p(x)$ smaller than v_c

$1 - x_c$ = fraction of particles with $v_p(x)$ greater than v_c

Removal of particles in sedimentation basins

- Measuring settling velocities
  - A large gradation of particle sizes for wastewater
  - Not easy to estimate terminal settling velocities of a large range of particles using theoretical calculations
  - Flocculant settling occurs in primary sedimentation basins
  - Measure the settling velocities using a settling column test and construct a settling curve



Removal of particles in sedimentation basins

Q: Determine the removal efficiency for a sedimentation basin with an overflow rate of 2 m/h. The settling velocity distribution for the particles in the wastewater is provided below.

Settling velocity, m/h	Number of particles per liter x 10^{-5}
0.0-0.5	30
0.5-1.0	50
1.0-1.5	90
1.5-2.0	110
2.0-2.5	100
2.5-3.0	70
3.0-3.5	30
3.5-4.0	20
total	500

Grit removal

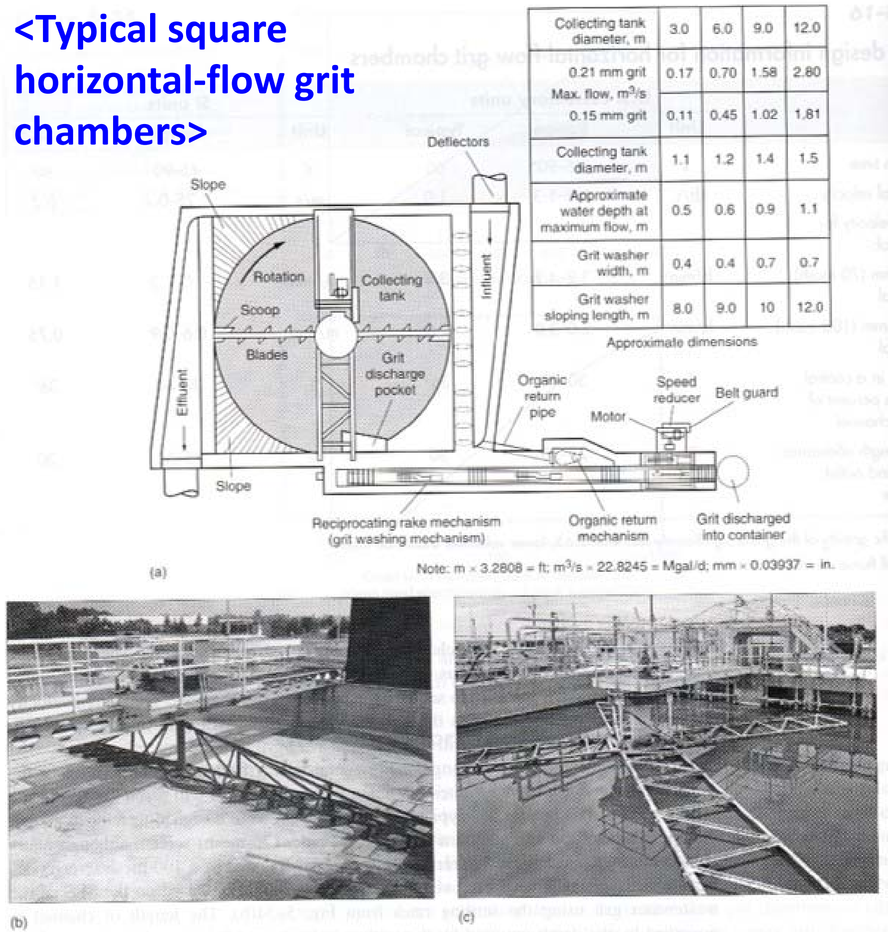
- Grit: sand, gravel, cinders, or other heavy solid materials that have settling velocities substantially greater than those of the organic solids in wastewater

- **Necessity of grit removal**
  - Reduce formation of heavy deposits in reactors, pipelines, and channels
  - Reduce the frequency of digester cleaning caused by excessive accumulations of grit
  - Protect moving mechanical equipment from abrasion and accompanying abnormal wear

Types of grit chambers

- **Horizontal-flow grit chambers**
  - Rectangular horizontal-flow grit chambers: oldest type, velocity-controlled
  - Square horizontal-flow grit chambers

<Typical square horizontal-flow grit chambers>



Collecting tank diameter, m	3.0	6.0	9.0	12.0
Max. flow, m³/s: 0.21 mm grit	0.17	0.70	1.58	2.80
0.15 mm grit	0.11	0.45	1.02	1.81
Collecting tank diameter, m	1.1	1.2	1.4	1.5
Approximate water depth at maximum flow, m	0.5	0.6	0.9	1.1
Grit washer width, m	0.4	0.4	0.7	0.7
Grit washer sloping length, m	8.0	9.0	10	12.0

Figure 5-35
Typical square horizontal-flow grit chambers: (a) schematic with design information based on clean grit with a specific gravity of 2.65, (b) view of empty basin. The two rakes are used to move settled grit to the periphery for removal and (c) view of square grit chamber.

Types of grit chambers

- **Aerated grit chambers**
  – Air is introduced along one side of a rectangular tank to create a spiral flow pattern

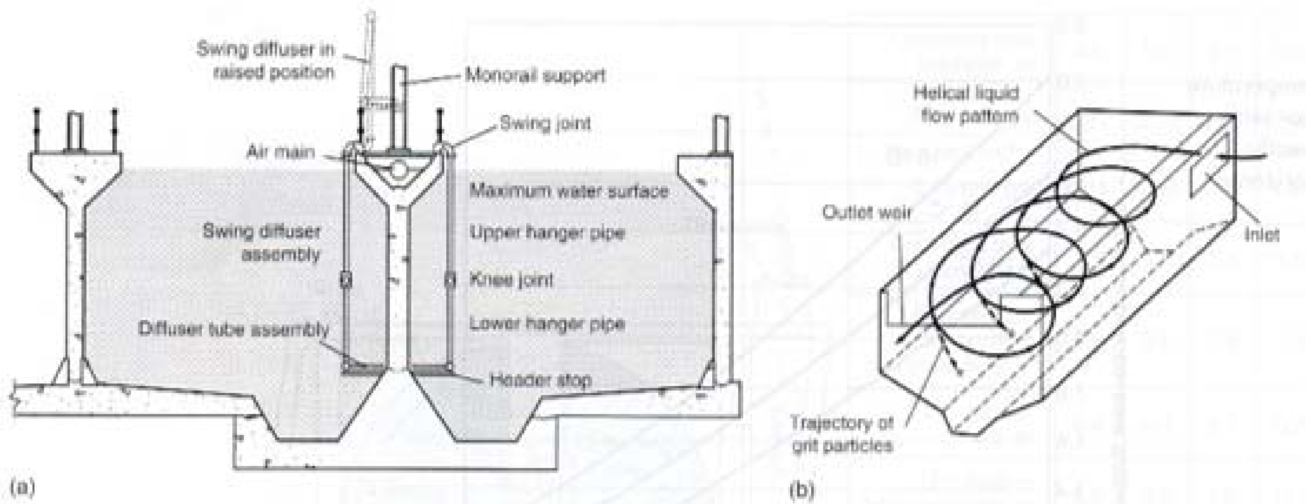


Figure 5-37

Typical aerated grit chamber: (a) cross-section through grit chamber and (b) schematic of helical flow pattern through an aerated grit chamber.

Types of grit chambers

- **Vortex-type grit chambers**
  - Mechanically induced vortex: a rotating turbine impeller enhances the toroidal motion
  - Hydraulically induced vortex: vortex is generated by the flow entering the unit

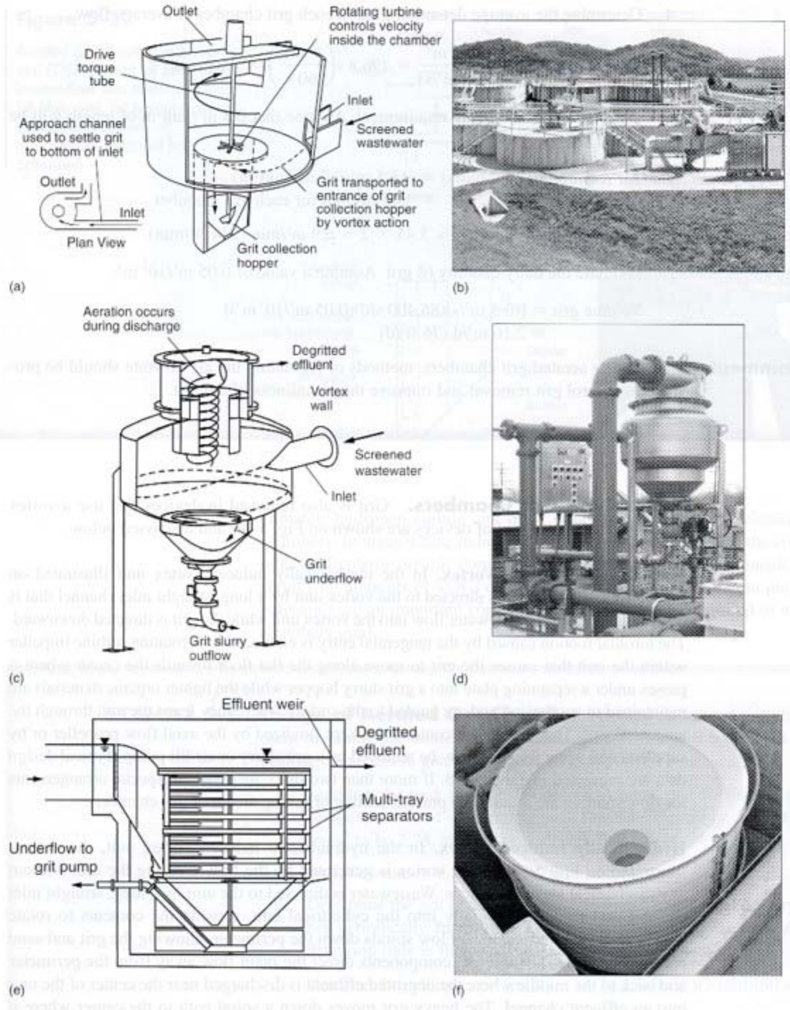


Figure 5–40

Vortex-type grit chambers: (a) schematic Pista® Grit Separator (adapted from Smith & Loveless), (b) view of typical installation (courtesy of Smith & Loveless) (c) schematic of Eutek TeaCup® separator (adapted from Hydro International), (d) view of Eutek TeaCup® separator (courtesy of Hydro International), (e) section through seven-tray Eutek HeadCell® grit separator, and (f) view of Eutek HeadCell of tray grit separator (courtesy of Hydro International).

Primary sedimentation

- **Objective**
  - Remove readily settleable solids and floating material in wastewater
  - Removes 50-70% of SS and 25-40% of BOD

- Sedimentation tanks are also used for…
  - **CSO and stormwater treatment**
    - Apply moderate retention time (10-30 min) to remove a substantial portion of the organic solids in CSO or stormwater before direct discharge
  - **Secondary treatment**
    - Settling of microbial "floc"

Types of primary sedimentation tanks

- **Rectangular tanks**

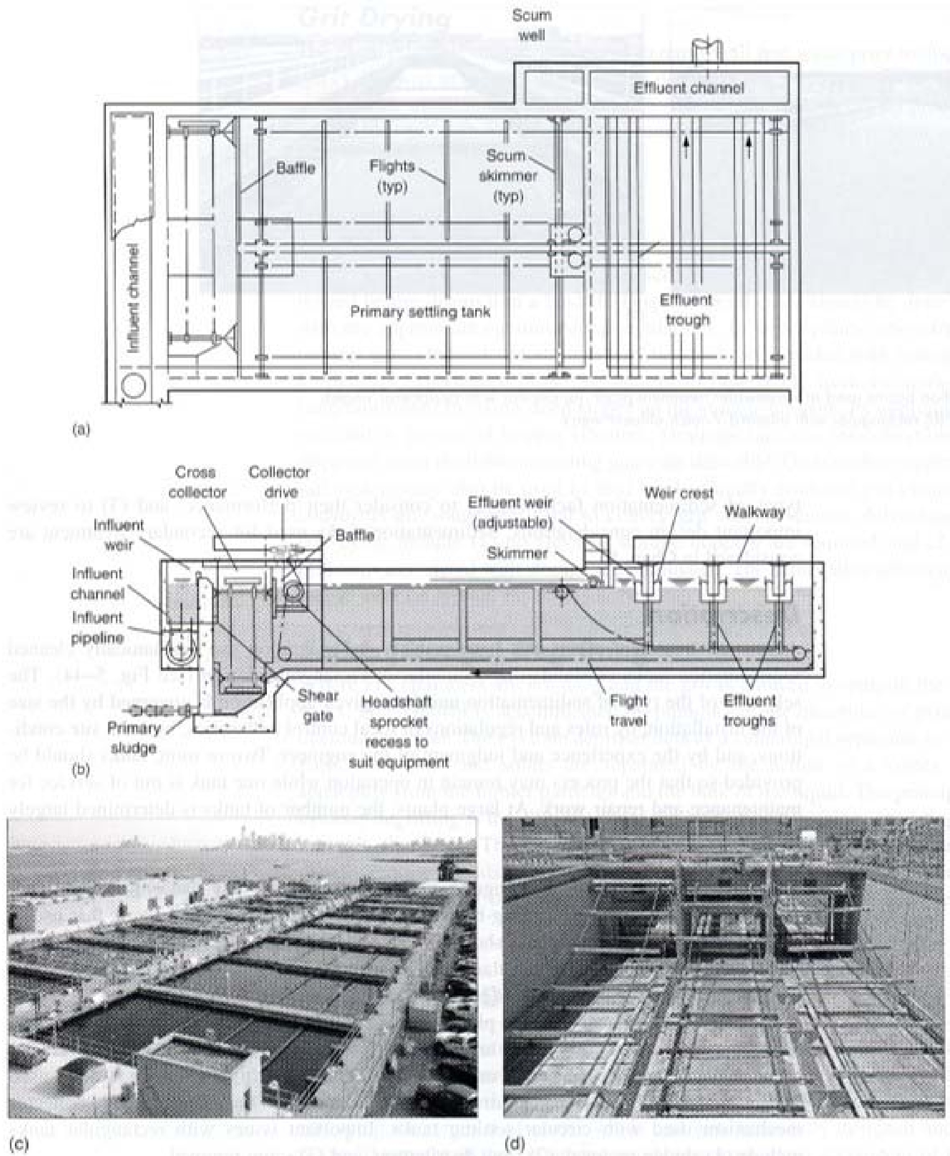


Figure 5-45
Typical rectangular primary sedimentation tank: (a) plan, (b) section, (c) view of large rectangular sedimentation tank with weirs similar to those shown on (b), and (d) view of empty tank with sludge removal mechanism.

Types of primary sedimentation tanks

- **Circular tanks**
  - Both center-feed and periphery-feed types are applicable (center-feed more common)

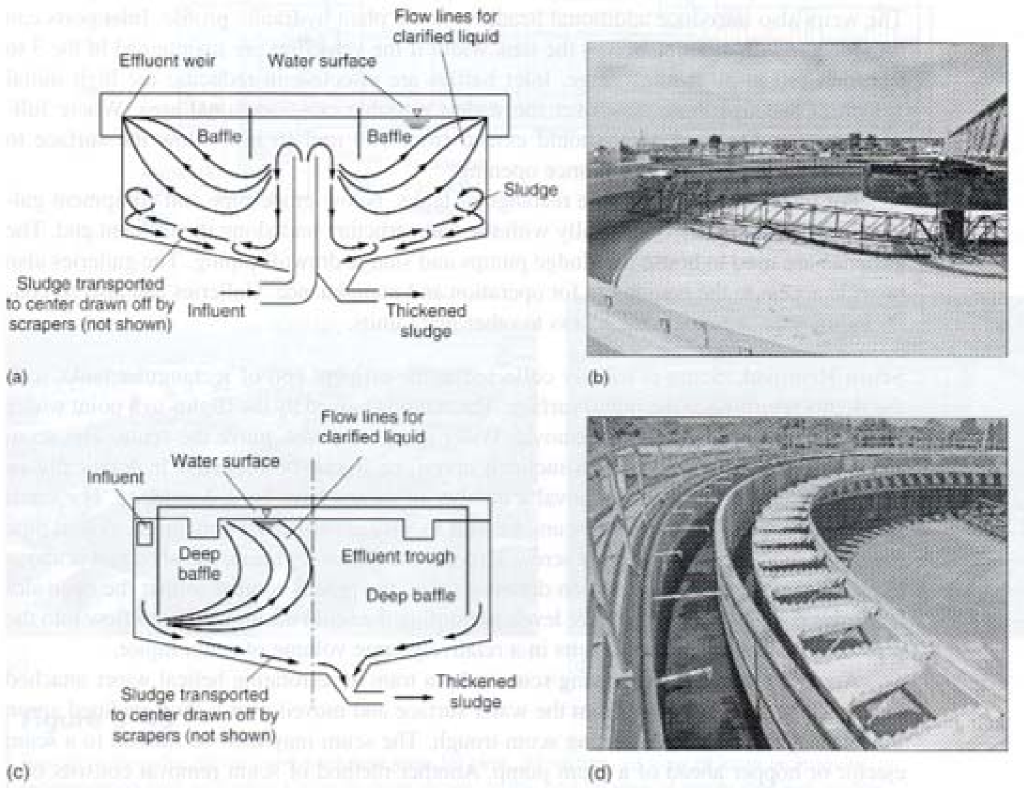


Figure 5-46

Typical circular sedimentation tanks: (a) schematic of center feed, (b) view of center feed unit, (c) schematic of peripheral feed, and (d) view of a peripheral feed unit.

Primary sedimentation - considerations

- Flow distribution
  - Maintain calm, consistent flow with less turbulence esp. at inlet & outlet
  - Minimize vertical flow (minimize sludge resuspension)
  - Examples of inlet designs for rectangular tanks
    - Full-width inlet channels with inlet weirs
    - Inlet channels with submerged ports or orifices
    - Inlet channels with wide gates and slotted baffles

- Sludge removal
  - How to collect settled sludge and where to install pumping facilities

- Scum removal
  - How to collect scum and remove it – manually or automatically?

Primary sedimentation – design considerations

- **Hydraulic retention time**

$$\tau = \frac{V}{Q}$$

τ = HRT (hr)
V = effective tank volume (m^3)
Q = flowrate (m^3/hr)

- **Overflow rate (surface loading rate)**
  - Set based on target particle type and size to be removed (recall the gravity settling theory)

$$v_o = \frac{Q}{A}$$

v_o = overflow rate (m^3/m^2-d)
A = horizontal tank surface area (m^2)

Primary sedimentation – design considerations

[Typical design information for primary sedimentation tanks]

Item	Unit	Range	Typical
Primary sedimentation tanks followed by secondary treatment			
HRT	h	1.5-2.5	2.0
Overflow rate	$m^3/m^2/d$		
Average flowrate		30-50	40
Peak hourly flowrate		80-120	100
Primary settling with waste activated sludge return			
HRT	h	1.5-2.5	2.0
Overflow rate	$m^3/m^2/d$		
Average flowrate		24-32	28
Peak hourly flowrate		48-70	60

Primary sedimentation – design considerations

- **Scour velocity: should be kept low to avoid resuspension**

$$v_H = \left[\frac{8k(s-1)gd}{f}\right]^{1/2}$$

v_H = horizontal velocity that will just produce scour (m/s)

k = constant that depends on type of material being scoured (unitless); typical range 0.04-0.06

s = specific gravity of particles

g = gravity acceleration (9.81 m/s^2)

d = diameter of particles (m])

f = Darcy-Weisbach friction factor (unitless); typical range 0.02-0.03

Designing a primary sedimentation basin

Q: The average flowrate at a small municipal wastewater treatment plant is 20,000 m^3/d. Design rectangular primary clarifiers with a channel width of 6 m. Use a minimum of two clarifiers. Calculate the scour velocity, to determine if settled material will become resuspended. Use an overflow rate of 40 $m^3/m^2/d$ and a side water depth of 4 m. To calculate scour velocity, use k = 0.05, s = 1.25, d = 100 µm, and f = 0.025.

Flotation

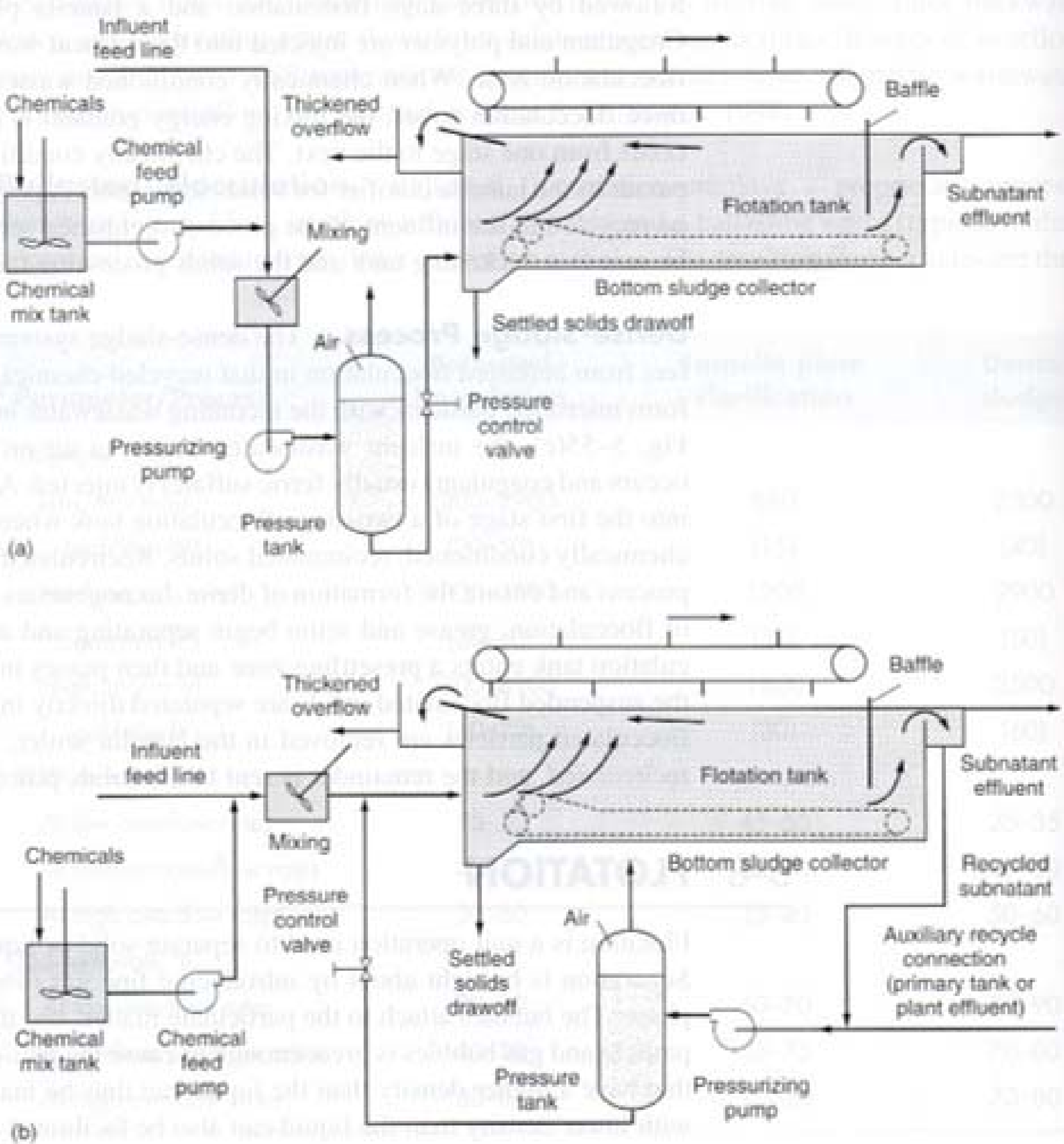
- Objective: separate solid or liquid particles from wastewater by **causing the particles to rise to the water surface**
- Fine air bubbles are introduced; the bubbles attach to particles to increase the buoyant force
- Good for particles having **slow settling velocity** (light and/or small)
- Particles floated to the surface are collected by a skimming operation
- Major application
  - Remove SS
  - Concentrate biosolids (sludge)

Types of flotation unit processes

- **Dissolved-Air Flotation (DAF)**
  - Air is dissolved in the wastewater under a pressure of several atms (high P → high gas solubility)
  - The gas-laden wastewater then flows to a flotation tank under atmospheric pressure (low P → low gas solubility → generation of fine bubbles)

Figure 5–56

Schematic of dissolved-air flotation systems: (a) without recycle in which the entire flow is passed through the pressurizing tank and (b) with recycle in which only the recycle flow is pressurized. The pressurized flow is mixed with the influent before being released into the flotation tank.



Types of flotation unit processes

- **Dissolved-Air Flotation (DAF)**
  - Design and operation parameter: air to solids ratio (A/S)
    - Performance depends primarily on A/S
    - Typical range of A/S from 0.005 to 0.060 (depending on the types of solids)
    - When all flow is pressurized (w/o recycle):

$$A/S = \frac{1.3 s_a (fP - 1)}{S_a}$$

A/S = air to solids ratio (mL air/mg solids)
s_a = air solubility (mL/L)
f = fraction of air dissolved at pressure P, usually 0.5
P = pressure (atm) = $(p + 101.35)/101.35$
p = gage pressure (kPa)
S_a = influent SS (mg/L)

    - When only recycle flow is pressurized:

$$A/S = \frac{1.3 s_a (fP - 1) R}{S_a Q}$$

R = pressurized recycle (m^3/d)
Q = mixed-liquor flow (m^3/d)

DAF process

Q: Design a flotation thickener without pressurized recycle to thicken the soilds in activated-sludge mixed liquor from 0.3 to about 4 percent. Assume following conditions apply:

1. Optimum A/S ratio = 0.008 mL/mg
2. Air solubility = 18.7 mL/L (at 20°C)
3. Fraction of saturation = 0.5
4. Surface loading rate = 8 L/m^2/min
5. Sludge flowrate = 400 m^3/d

DAF process

Answer)

Determine the required gage pressure:

$$0.008\ mL/mg = \frac{1.3(18.7\ mL/L)(0.5P - 1)}{3000\ mg/L}$$

$$P = 3.98\ atm = \frac{p + 101.35}{101.35}$$

$$p = 302\ kPa$$

Determine the required surface area:

$$A = \frac{(400\ m^3/d)(10^3\ L/m^3)}{(8\ L/m^2/min)(1440\ min/d)} = 34.7\ m^2$$

Types of flotation unit processes

- **Dispersed-Air Flotation**
  - A revolving impeller forces water through disperser openings and creates a vacuum in the standpipe
  - The vacuum pulls air into the standpipe and mixes it with the water
  - Fine bubbles are created by a mixing force and by the movement of the fluid through a series of cells
  - Less frequently used – mainly used in industrial wastewater treatment