## Wastewater Engineering

## Class 5 Primary Sedimentation

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## Theoretical Analysis



### General solids liquid sedimentation separation

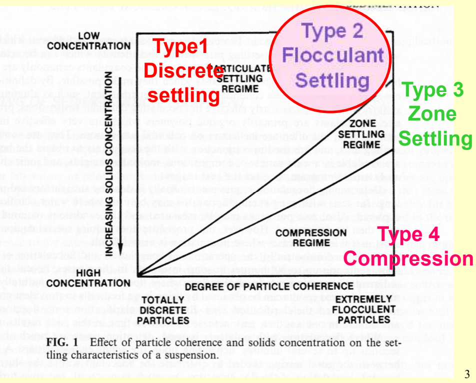



FIG. 1 Effect of particle coherence and solids concentration on the settling characteristics of a suspension.

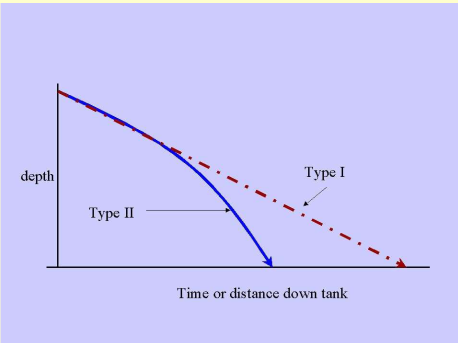


TABLE 6-8
Types of settling phenomena involved in wastewater treatment

| Type of settling phenomenon | Description | Application/occurrence | |
|---|---|---|---|
| Discrete particle (type 1) | Refers to the sedimentation of particles in a suspension of low solids concentration. Particles settle as individual entities, and there is no significant interaction with neighboring particles | Removes grit and sand particles from wastewater | Sand or grit removal |
| Flocculant (type 2) | Refers to a rather dilute suspension of particles that coalesce, or flocculate, during the sedimentation operation. By coalescing, the particles increase in mass and settle at a faster rate | Removes a portion of the suspended solids in untreated wastewater in primary settling facilities, and in upper portions of secondary settling facilities. Also removes chemical floc in settling tanks | Primary sedimentation |
| Hindered, also called zone (type 3) | Refers to suspensions of intermediate concentration, in which interparticle forces are sufficient to hinder the settling of neighboring particles. The particles tend to remain in fixed positions with respect to each other, and the mass of particles settles as a unit. A solids-liquid interface develops at the top of the settling mass | Occurs in secondary settling facilities used in conjunction with biological treatment facilities | Activated sludg settling |
| Compression (type 4) | Refers to settling in which the particles are of such concentration that a structure is formed, and further settling can occur only by compression of the structure. Compression takes place from the weight of the particles, which are constantly being added to the structure by sedimentation from the supernatant liquid | Usually occurs in the lower layers of a deep sludge mass, such as in the bottom of deep secondary settling facilities and in sludge-thickening facilities | Sludge Thickening |

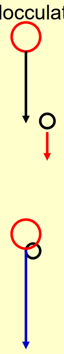


### Comparison of Type I and II sedimentation






Flocculation settling – both OR and depth is important



Settling / flocculation provides better separation with depth

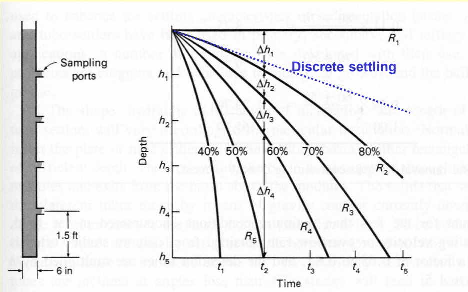



FIGURE 6-12
Settling column and settling curves for flocculant particles.

## Primary Sedimentation System Design



## Primary Sedimentation

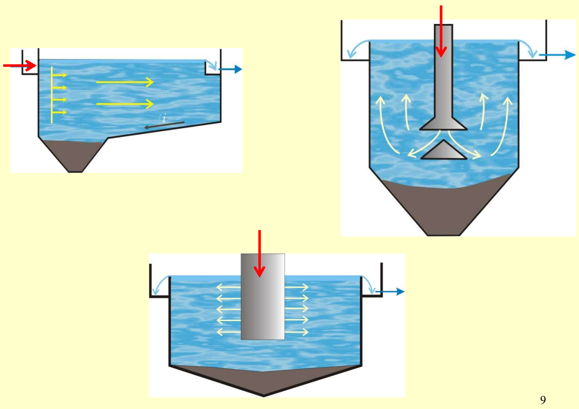
Objective: To remove settleable organic solids in large basins under relatively quiescent conditions

- Removal efficiency
  - $BOD_5$: 30~40%
  - TSS: 50~70%
- Settled solids: collected by mechanical scrapers into a hopper, from which they are pumped to a sludge-processing area.
- Oil, grease, and other floating materials: skimmed from the surface
- Effluent: discharged over weirs into a collection trough

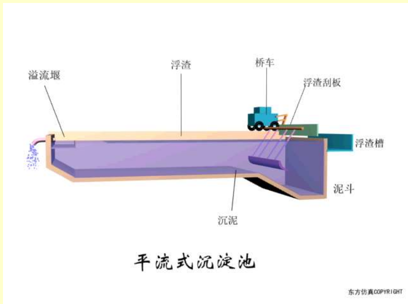
Types of primary sedimentation tanks

- Horizontal flow
- Solids contact
- Inclined surface

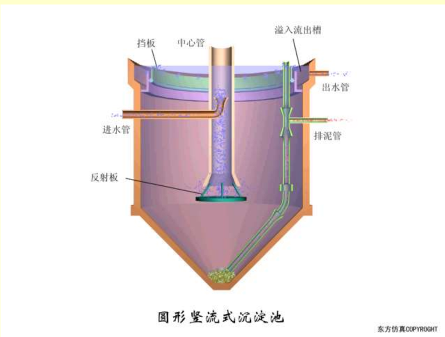




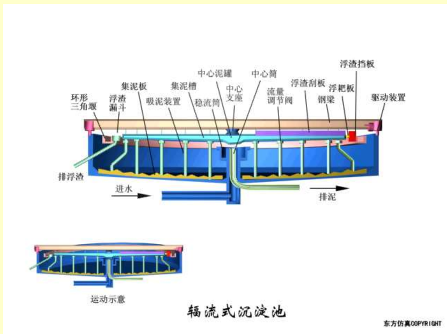




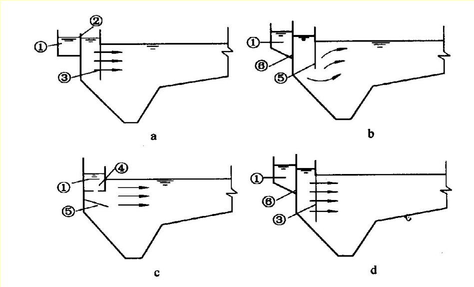




## Influent



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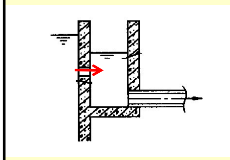
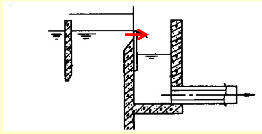
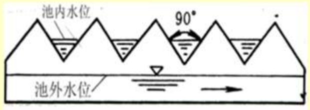
## Effluent



淹没式出水孔口



自由堰




三角堰

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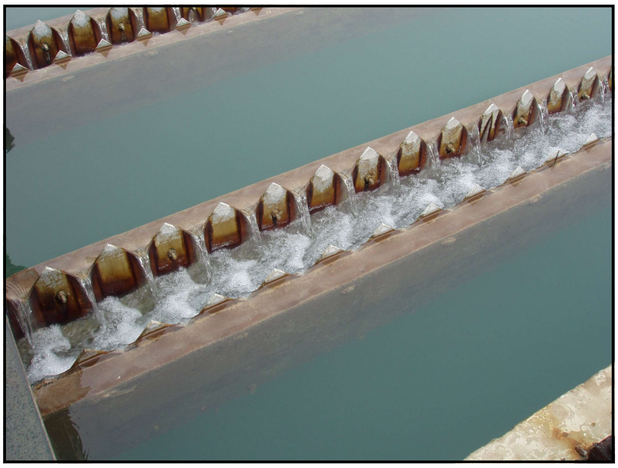
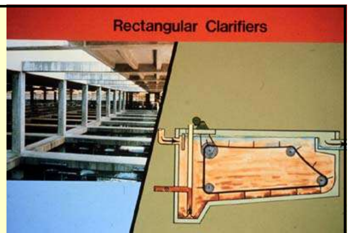
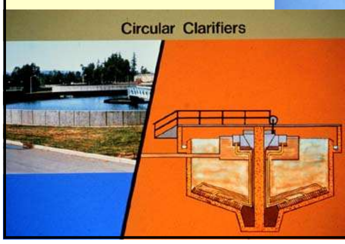



## Horizontal Flow Sedimentation Tanks

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## Horizontal Flow

**Advantages**

- Occupy less land area when multiple units are used
- Provide economy by using common walls for multiple units
- Easier to cover the units for odor control
- Provide longer travel distance for settling to occur
- Less short-circuiting
- Lower inlet-outlet losses
- Less power consumption for sludge collection and removal mechanisms

**Disadvantages**

- Possible dead spaces
- Sensitive to flow surges
- Restricted in width by collection equipment
- Require multiple weirs to maintain low weir loading rates
- High upkeep and maintenance costs of sprockets, chain, and flights used for sludge removal

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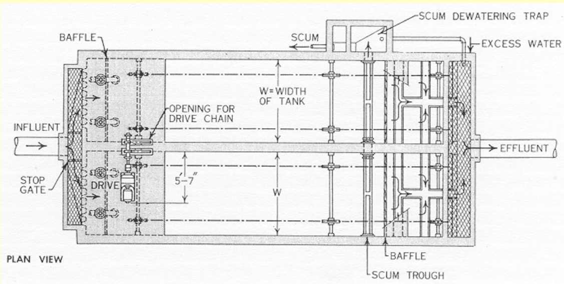
## Horizontal Flow Rectangular Sedimentation Tank

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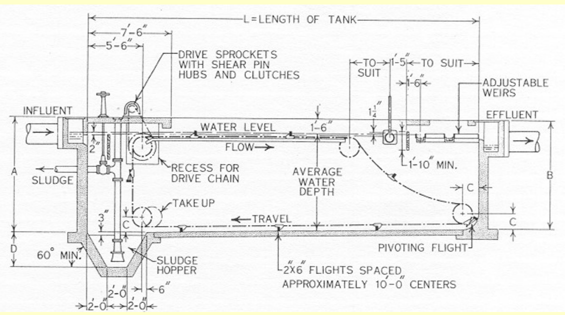
## Horizontal Flow Rectangular Sedimentation Tank




Longitudinal section with skimmer

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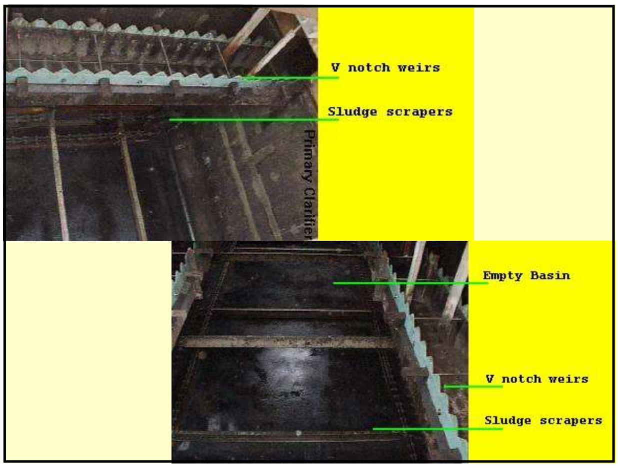
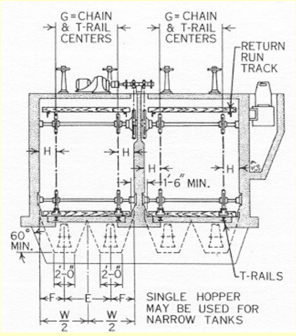


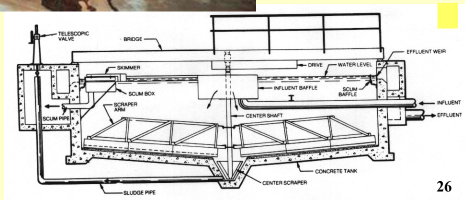
## Horizontal Flow Rectangular Sedimentation Tank




Cross section



**Horizontal flow circular clarifier**

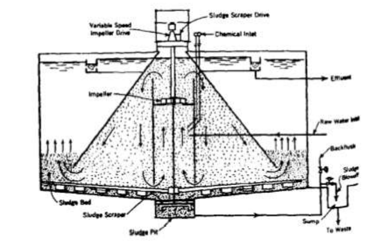





## Solids Contact Clarifier

- Incoming solids rise and come in contact with the solids in the sludge layer. This layer acts as a blanket, and the incoming solids agglomerate and remain enmeshed within this blanket. The liquid rises upward while a distinct interface retains the solids below.
- Better hydraulic performance and shorter detention time for equivalent solids removal in horizontal flow clarifiers.
- Either circular or rectangular
- Not suitable for biological sludges because long sludge-holding times may create undesirable septic conditions.






## Solids-Contact Clarifier

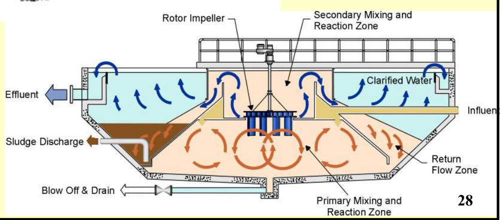





**Table 5–20**
Typical design information for primary sedimentation tanks[a]

| Item | U.S. customary units: Unit | Range | Typical | SI units: Unit | Range | Typical |
|---|---|---|---|---|---|---|
| **Primary sedimentation tanks followed by secondary treatment** | | | | | | |
| Detention time | h | 1.5–2.5 | 2.0 | h | 1.5–2.5 | 2.0 |
| Overflow rate | | | | | | |
| Average flow | gal/ft$^2$·d | 800–1200 | 1000 | m$^3$/m$^2$·d | 30–50 | 40 |
| Peak hourly flow | gal/ft$^2$·d | 2000–3000 | 2500 | m$^3$/m$^2$·d | 80–120 | 100 |
| Weir loading | gal/ft·d | 10,000–40,000 | 20,000 | m$^3$/m·d | 125–500 | 250 |
| **Primary settling with waste activated-sludge return** | | | | | | |
| Detention time | h | 1.5–2.5 | 2.0 | h | 1.5–2.5 | 2.0 |
| Overflow rate | | | | | | |
| Average flow | gal/ft$^2$·d | 600–800 | 700 | m$^3$/m$^2$·d | 24–32 | 28 |
| Peak hourly flow | gal/ft$^2$·d | 1200–1700 | 1500 | m$^3$/m$^2$·d | 48–70 | 60 |
| Weir loading | gal/ft·d | 10,000–40,000 | 20,000 | m$^3$/m·d | 125–500 | 250 |

[a] Comparable data for secondary clarifiers are presented in Chap. 8.



**Design overflow rates for sedimentation tanks (m$^3$/m$^2$·day)**

| Condition | Range | Typical |
|---|---|---|
| **Primary sedimentation prior to secondary treatment** | | |
| **Average flow** | **30~50** | **40** |
| **Peak flow** | **70~130** | **100** |
| **Primary sedimentation with WAS return** | | |
| **Average flow** | **25~35** | **30** |
| **Peak flow** | **45~80** | **60** |

**Detention Times for Various Overflow Rates and Tank Depth**

| Overflow rate (m$^3$/m$^2$·day) | Detention period (hrs): 2-m depth | 2.5-m depth | 3-m depth | 3.5-m depth | 4-m depth | 4.5-m depth |
|---|---|---|---|---|---|---|
| 30 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.6 |
| 40 | 1.2 | 1.5 | 1.8 | 2.1 | 2.4 | 2.7 |
| 50 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | 2.2 |
| 60 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 |
| 70 | 0.7 | 0.9 | 1.0 | 1.2 | 1.4 | 1.5 |
| 80 | 0.6 | 0.8 | 0.9 | 1.1 | 1.2 | 1.4 |

Detention time at average design flow
- Primary sedimentation tanks - 1~2 hrs
- Secondary clarifiers - 2~4 hrs

## Design Parameters

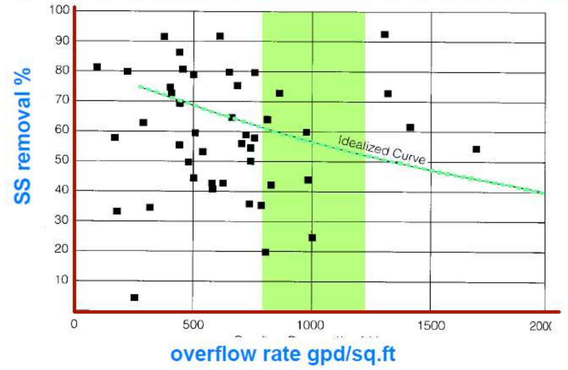
- **US**

| | Overflow rate | | Detention Time |
|---|---|---|---|
| | m/h | gpd/ft² | h |
| Max. Average Daily Flow | 1.3 - 2 | 780 - 1200 | 1.5 - 2.5 |
| Peak (Hourly) Flow | 3.3 - 5 | 2000 - 3000 | |

- **Germany**

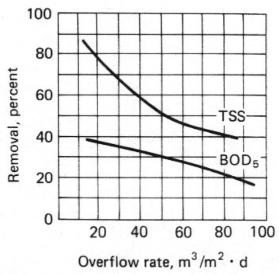
| | Overflow rate (m/h) | | Detention Time (h) |
|---|---|---|---|
| | rectangular | radial | |
| Followed by: | | | |
| trickling filters | < 1.3 | 0.8 - 1.3 | 1.5 - 2.5 |
| activated sludge | < 4.0 | 2.5 - 4 | 1.5 - 2 |

## Performance

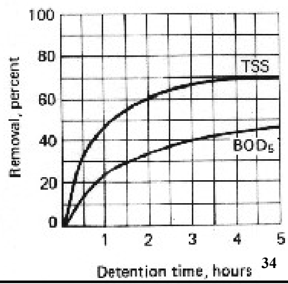



## Enhanced Primary Settling

| | | Advanced primary performance | | | | | | Chemical addition | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | BOD | | | TSS | | | | | |
| | Flow | Inf | Eff | Rem | Inf | Eff | Rem | $FeCl_3$ | Polymer | Duration |
| Location | mgd | mg/l | mg/l | % | mg/l | mg/l | % | mg/l | mg/l | |
| Point Loma, San Diego | 191 | 276 | 119 | 56.9 | 305 | 60 | 80.3 | 35 | 0.26 | Continuous |
| Orange County Plant No. 1 | 60 | 263 | 162 | 38.4 | 229 | 81 | 64.6 | 20 | 0.25 | 8 h peak |
| Orange County Plant No. 2 | 184 | 248 | 134 | 46.0 | 232 | 7 | 69.4 | 30 | 0.14 | 12 h peak |
| JWPCP Los Angeles Co. | 380 | 365 | 210 | 42.5 | 475 | 105 | 77.9 | 0 | 0.15 | Continuous |
| Hyperion, Los Angeles | 370 | 300 | 145 | 51.7 | 270 | 45 | 83.3 | 20 | 0.25 | Continuous |
| Sarnia, Ontario, Canada | 10 | 98 | 49 | 50.0 | 124 | 25 | 79.8 | 17 | 0.30 | Continuous |




**$BOD_5$ and TSS Removal Efficiency with Respect to Overflow Rate and Detention Time**






## Design Factors - continued

**Weir loading rate (< 370 m³/m²·day) (Ten-States Standards)**
**124 m³/m²·day for plants designed for average design flow of ≤ 44 L/sec**
**186 m³/m²·day for plants designed for average design flow of > 44 L/sec**

**Dimensions**

| Type | Range | Typical |
|---|---|---|
| **Rectangular** | | |
| **Length, m** | **10~100** | **25~60** |
| **Length-to-width ratio** | **1~7.5** | **4** |
| **Length-to-depth ratio** | **4.2~25** | **7~18** |
| **Sidewater depth, m** | **2.5~5** | **3.5** |
| **Width, m** | **3~24** | **6~10** |
| **Clarifier** | | |
| **Diameter, m** | **3~60** | **10~40** |
| **Side depth, m** | **3~6** | **4** |

**Solids Loading**
**Not an important deciding factor for primary sedimentation tank design**
**Primary sedimentation tanks: 1.5~34 kg/m²·day**
**Secondary clarifiers: 49~98 kg/m²·day**

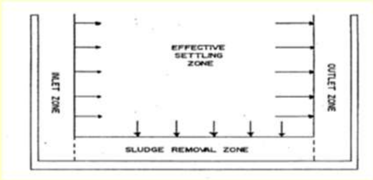


## Design Factors

✓Design Objective: provide sufficient time under quiescent conditions for maximum settling to occur.

***Conditions causing decrease in solids removal efficiency***

- Eddy currents induced by incoming fluid
- Surface currents provided by wind action
- Vertical currents induced by outlet structure
- Vertical convection currents induced by the temperature difference between the influent and the tank contents
- Density currents causing cold or heavy water to underrun a basin, and warm or light water to flow across its surface
- Currents induced due to the sludge scraper and sludge removal system



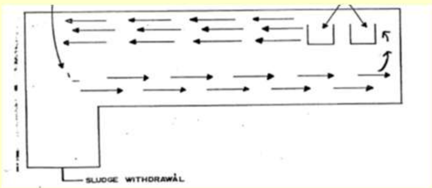
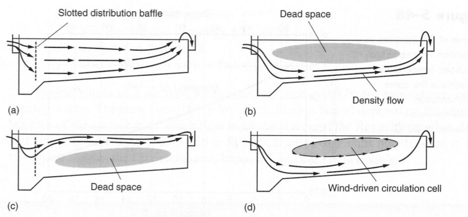






**Figure 5-47**
Typical flow patterns observed in rectangular sedimentation tanks: (*a*) ideal flow, (*b*) effect of density flow or thermal stratification (water in tank is warmer than influent), (*c*) effect of thermal stratification (water in tank is colder than influent), and (*d*) formation of wind-driven circulation cell. (*Crites and Tchobanoglous, 1998.*)






$$R = \frac{t}{a + bt}$$

- R = expected removal efficiency;
- t = nominal detention time T;
- a, b = empirical constant.

For example, at 20 ° C,

| Item | a | b |
|---|---|---|
| BOD | 0.018 | 0.020 |
| TSS | 0.0075 | 0.014 |

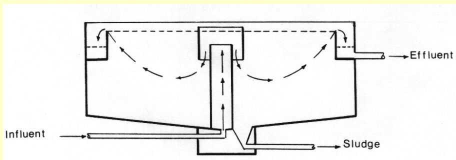


## Design Factors - continued

**Influent structure**

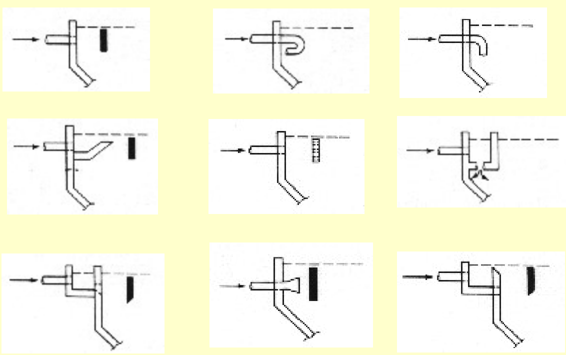
- Dissipate energy in incoming flow by means of baffles or stilling basin
- Distribute flow equally along the width
- Prevent short circuiting by disturbing thermal and density stratification
- Provide small head loss

✓ Provision for flow control, scum removal, and maintenance
✓ Velocity at inlet pipe: 0.3 m/sec






## Influent Structures

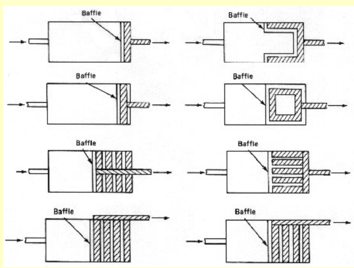




## Design Factors - continued

**Effluent structure**

- **Provide a uniform distribution of flow over a large area**
- **Minimize the lifting of the particles and their escape into the effluent**
- **Reduce the escape of floating matter to the effluent**




- **Weir loading for plants**
  **≤ 44 L/sec – 124 $m^3$/m·day**
  **> 44 L/sec - 186 $m^3$/m·day**
- **Straight or V-notches either one side or both sides of trough**
- **Baffle in front of the weir to stop the floating matter from escaping into the effluent**

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## Design Factors - continued

### Sludge collection

- **Bottom slope**: to facilitate draining of the tank and to remove the sludge toward the hopper. Rectangular tanks: 1~2%; circular clarifiers: 40~100 mm/m diameter
- **Equipment**

  **Rectangular tanks**
  - A pair of endless conveyor chains running over sprockets attached to the shafts or moving-bridge sludge collectors having a scraper to push the sludge into the hopper
  - Suction-type arrangement to withdraw the sludge from basins

  **Circular tanks**
  - Scraping mechanism with radial arms having plows set at an angle supported on center pier (≥ 10 m diameter) or on a beam spanning the tank (< 10 m diameter) (flight travel speed - 0.02~0.06 revolution/min)
  - Suction-type units for handling light sludge.

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## Conveyor Chain

✓ One endless chain is connected to a shaft and a drive unit.
✓ Linear conveyor speed is 0.3~1 m/min for primary and 0.3 m/min for secondary clarifier
✓ Cross-wood (flights) (5 cm thick and 15~20 cm deep) are attached to the chain at 3-m intervals and are up to 6 m in length.
✓ For tanks greater than 6 m in width, multiple pairs of chains are used.
✓ The floating material is pushed in opposite direction of sludge and is collected in a scum collection box.
✓ **Advantages**: simple to install, low power consumption, efficient scum collection, and suitable for heavier sludge
✓ **Disadvantages**: high maintenance cost of chain and flight removal mechanism, dewatering of tanks for gear and chain repair, and potential resuspension of light sludge

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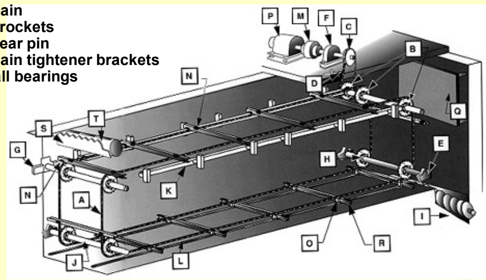
## Chain-and-Flight Sludge Collector

**A. Chain**
**B. Sprockets**
**C. Shear pin**
**D. Chain tightener brackets**
**E. Wall bearings**



**F. Pillow block bearings**
**G. Sewage take-up bearing**
**H. Set collars**
**I. Screw conveyer**
**J. Shafting**
**K. Return rail system**
**L. Floor rail wear strip**
**M. Couplings**
**N. Wear shoes**
**O. Filler blocks**
**P. Gear box**
**Q. Baffles**
**R. Flights (fiberglass or wood)**
**S. Weirs**
**T. Scum pipe**

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## Bridge Drive Scraper

✓ Standard traveling beam bridges for spans up to 13 m (40 ft) and truss bridge for spans over 13 span are used.
✓ Bridge travel is accomplished by the use of a gear motor.
✓ The wheels run on rails which are attached to the footing wall along each side wall of the basin.
✓ Mechanical scrapers or rakes are hung from the top carriage that push the sludge to the hopper.
✓ Separate blades are provided on top to move the scum.
✓ **Advantages**: all moving mechanisms above water, scraper repair or replacement without dewatering tanks, no width restrictions, longer operation life, and lower maintenance cost in low-span bridges.
✓ **Disadvantages**: high power requirement, not suitable for cold weather (ice formation in tanks), and frequent break-down due to wheel climbing over rails in long-span bridges.

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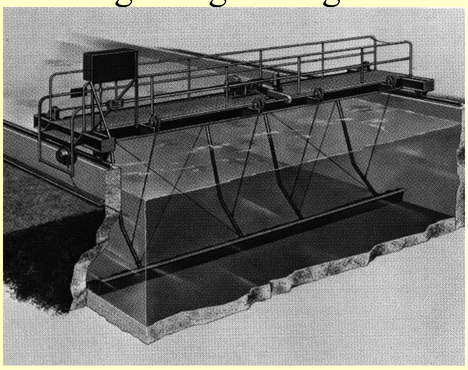
## Traveling Bridge Sludge Collector



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## Bridge Drive Sludge Suction

- ✓ The bridge design is similar to the bridge drive scraper.
- ✓ The sludge removal mechanisms are attached to the bridge and provide continuous removal of sludge along the length of travel.
- ✓ Pump, siphon, or airlift arrangements are used to suck and remove the sludge.
- ✓ **Advantages**: Better pickup of light sludge, all moving mechanisms above water, scraper repair or replacement without dewatering tanks, no width restrictions, longer operation life, and lower maintenance cost in low-span bridges, and suitable for biological and chemical sludges.
- ✓ **Disadvantages**: high power requirement, not suitable for cold weather (ice formation in tanks), and frequent break-down due to wheel climbing over rails in long-span bridges, and not used in primary sedimentation tanks.

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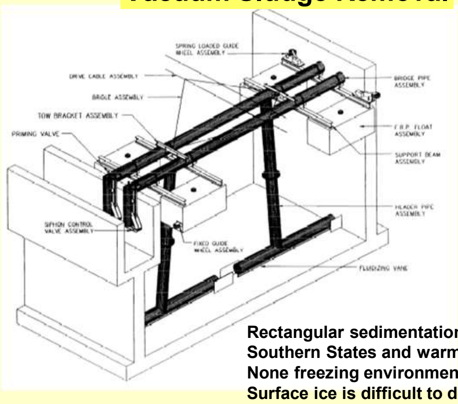
## Vacuum Sludge Removal



**Rectangular sedimentation basins**
**Southern States and warm climate areas**
**None freezing environments**
**Surface ice is difficult to design for**

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## Vacuum Sludge Removal

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## Design Factors - continued

### Sludge Removal

- Removed by means of a pump.

### Design considerations

- – Provision of continuous sludge pumping is desirable.
- – Each sludge hopper should have individual sludge withdrawal line at least 15 cm in diameter.
- – In rectangular tanks, cross-collectors are preferred over multiple hoppers.
- – Screw conveyors for sludge removal are also used.
- – An automatic control of sludge pump or siphon pipes using a photocell-type or sonic-type sludge blanket detector is desirable, especially for secondary clarifiers.
- – The sludge pump used are self-priming centrifugal and normally discharge into a common manifold. One sludge pumping station can serve two rectangular sedimentation tanks. The circular clarifiers are normally arranged in groups of two or four.

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## Design Factors - continued

### Scum removal

- Generally pushed off the surface to a collection sump. In rectangular tanks, the scum is normally pushed in the opposite direction by the flights of the sludge mechanism in its return travel. In circular clarifiers, the scum is removed by a radial arm which rotates on the surface with the sludge removal equipment. Sometimes, removed by water sprays.
- Scraped manually or mechanically up an inclined apron.
- All effluent weirs have baffles to stop the loss of scum into the effluent.
- The scum has a specific gravity of 0.95. Solids content may vary from 25 to 60%.
- The quantity of scum varies from 2 to 13 kg/$10^3$ $m^3$ (17~110 lb/million gallon).
- Pipings are often glass-lined and kept reasonably warm to minimize blockage.
- Scum has been digested in aerobic and anaerobic digesters.

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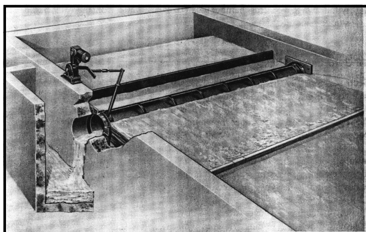
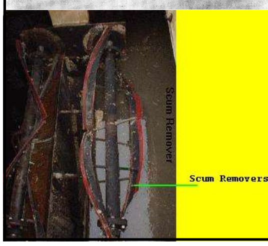
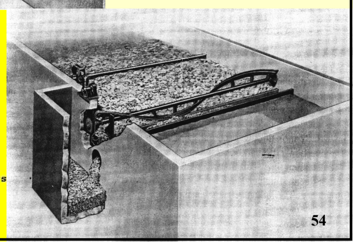


## Scum Collection and Removal Arrangements



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## Information Checklist

- ✓ Average and peak design flows including the returned flows from other treatment units
- ✓ All sidestreams from thickener, digester, and dewatering facility
- ✓ Treatment plant design criteria prepared by the concerned regulatory agencies
- ✓ Equipment manufacturers and equipment selection guide
- ✓ Information on the existing facility if the plant is being expanded
- ✓ Available space and topographic map of the plant site
- ✓ Shape of the tank (rectangular, square, or circular)
- ✓ Influent pipe data, to include diameter, flow characteristics, and approximate water surface elevation or hydraulic grade line
- ✓ Headloss constrains for sedimentation facility

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## Common Operating Problems

1. Black and odorous septic wastewater due to decomposing wastewater in the collection system, recycle of excessively strong digester supernatant, or inadequate pretreatment of organic discharges from the industries → preaeration, chlorination, or hydrogen peroxide/ potassium permanganate oxidation, control of digester supernatant, and strict enforcement of industrial pretreatment regulations
2. Scum overflow due to inadequate frequency of scum removal, excessive industrial contribution, worn or damaged scum wiper blades, or improper alignment of the skimmer
3. Sludge that is hard to remove from the sludge hopper due to excessive grit accumulation → check the grit removal facility
4. Low solids in the sludge due to excessive sludge withdrawal, short circuiting, or surging flow
5. Excessive corrosion of metals due to $H_2S$ gas
6. Frequent broken scraper chain and shear pin failures due to improper shear pin sizing and flight alignment, ice formation, or excessive loading on the sludge scraper
7. A noise chain drive or a loose or stiff chain due to misalignment

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## Operation and Maintenance

1. Remove accumulations from the influent baffles, effluent weirs, scum baffles, and scum box each day.
2. Inspect all mechanical equipment at least once each shift.
3. Hose down and remove wastewater sludge and spills ASAP.
4. Determine sludge level and underflow concentration, and adjust primary sludge pumping rate accordingly.
4. Observe operation of scum pump and provide hosing as necessary.
5. Check daily electrical motors for overall operation, bearing temperature, and overload detector.
6. Check oil levels in gear reducers and bearings on a regular basis.
7. Drain each primary basin annually and inspect the underwater portion of the concrete structure and all mechanical parts.
8. Inspect all mechanical parts for wear, corrosion, and set proper clearance for flights at tank walls.
9. Clean and paint the exposed metal surfaces as necessary.

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