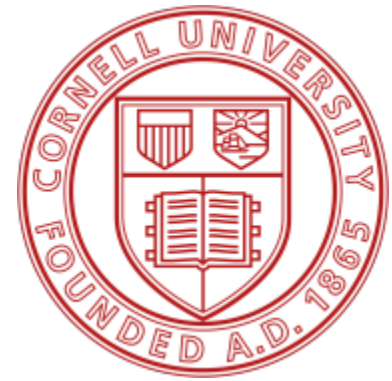


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Civil and Environmental Engineering



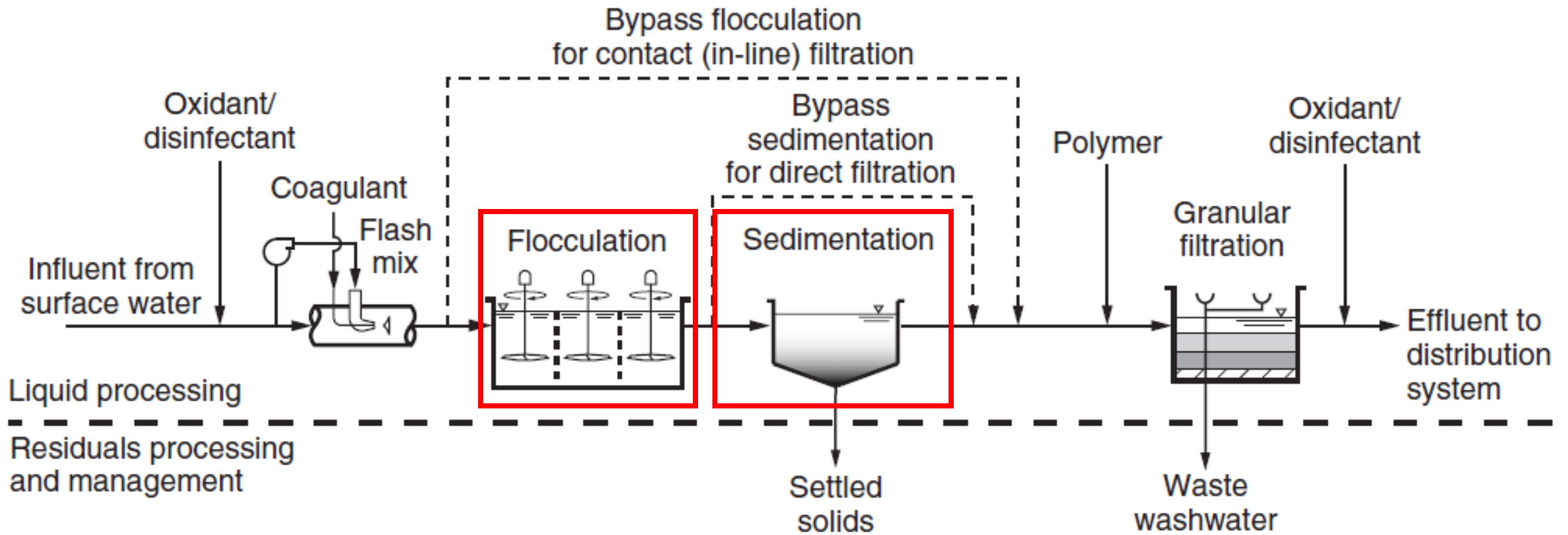
CEE 4540

Sustainable municipal drinking water treatment

Instruction: YuJung Chang
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Class #5 09/12/2018 2:55 – 4:10pm

Quick Review: Intake; Screening; Coagulation; and Sedimentation



Typical Design Criteria for Rectangular Tanks

Table 10-4

Typical design criteria for horizontal-flow rectangular tanks

Parameter	Units	Value
Type	—	Horizontal-flow rectangular tank
Minimum number of tanks	Unitless	2
Water depth	m (ft)	3–5 (10–16)
Length-to-depth ratio, minimum	Dimensionless	15:1
Width-to-depth ratio	Dimensionless	3:1–6:1
Length-to-width ratio, minimum	Dimensionless	4:1–5:1
Surface loading rate (overflow rate)	m ³ /h (gpm/ft ²)	1.25–2.5 (0.5–1.0) ←
Horizontal mean-flow velocity (at maximum daily flow)	m/min (ft/min)	0.3–1.1 (1–3.5)
Detention time	h	1.5–4
Launder weir loading	m ³ /m · h (gpm/ft)	9–13 (12–18) ^a
Reynolds number	Dimensionless	<20,000
Froude number	Dimensionless	>10 ⁻⁵
Bottom slope for manual sludge removal systems	m/m	1:300
Bottom slope for mechanical sludge scraper equipment	m/m	1:600
Sludge collector speed for collection path	m/min (ft/min)	0.3–0.9 (1–3)
Sludge collector speed for the return path	m/min (ft/min)	1.5–3 (5–10)

Source: Adapted from Kawamura (2000).

^aCan be higher, depending upon characteristics of floc.

Hydraulic Detention Time (HDT) for a Sed Basin

- Hydraulic Detention Time: The time for a drop of water to travel from inlet to outlet; or the length of time a drop of water will stay within the tank
 - Typical design value is 2 – 3 hours
 - $HDT = \text{Tank Volume (gal)} / \text{Flowrate (gpm)}$

Example 1: Calculate the Detention Time in for a clarifier with a volume of 25,000 gallons that receives a flow of 310,000 gal/day.

$$\begin{aligned} \text{Detention Time} &= \frac{\text{Volume}}{\text{Flow}} \\ &= \frac{25,000 \text{ gallons}}{310,000 \text{ gallons/day}} = 0.08 \text{ Days or } \sim 1.94 \text{ Hrs} \end{aligned}$$

Basic Terminologies & Calculations for “Loading Rates”

$$\text{Detention Time (DT)} = \frac{\text{Tank Volume, MG}}{\text{Flow into Tank, MGD}}$$

$$\text{Surface Overflow Rate (SOR)} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, ft}^2}$$

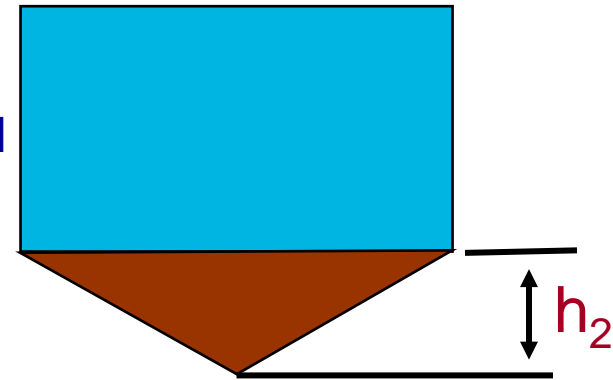
$$\text{Weir Overflow Rate (WOR)} = \frac{\text{Flow, gallons/day}}{\text{Length of Weir, ft}}$$

$$\text{Solids Loading Rate (SLR)} = \frac{\text{Solids, lbs/day}}{\text{Surface Area, ft}^2}$$

Basic Calculations for Tank Volume

- Surface area & Volume calculations for both rectangular and circular tanks is simple
- What if it's a cylinder tank with a cone bottom?
 - Cone bottom tanks is REQUIRED if there is potential solid settling

$$V_{\text{cylinder}} = \pi r^2 h_1 \longrightarrow h_1$$
$$V_{\text{cone}} = \frac{1}{3} \pi r^2 h \text{ or } \frac{\pi r^2 h_2}{3} \longrightarrow h_2$$
$$V_{\text{total}} = V_{\text{cylinder}} + V_{\text{cone}}$$



Cone Bottom Tank

Understanding “Hydraulic or Surface Loading Rates”

- How many gallons per minute (flow rate) is loading on per ft² of surface area
 - Focusing on how much water is “loaded” to the water surface of the tank
- Usually presented in gpm/ ft²

$$\text{HLR, gpm/ft}^2 = \frac{\text{Flow, gallons/min}}{\text{Surface Area, ft}^2}$$

- Also called “Surface Loading Rate” or “Surface Overflow Rate”
- Typical Value: 0.28 – 0.56 gpm/ft²

Example

Calculate the Hydraulic Loading Rate for a clarifier that is 50 ft long, 15 ft wide, 12 ft deep, and receives a flow of 338,000 gallons per day.

$$\text{SLR, gpd/ft}^2 = \frac{\text{Flow, gallons/day}}{\text{Surface Area, ft}^2}$$

$$\text{Surface Area, ft}^2 = 50 \text{ ft} \times 15 \text{ ft} = 750 \text{ ft}^2$$

$$\begin{aligned} \text{SOR, gpd/ft}^2 &= \frac{338,000 \text{ gallons per day}}{750 \text{ ft}^2} \\ &= 451 \text{ gpd/ft}^2 = 0.31 \text{ gpm/ft}^2 \end{aligned}$$

Clarifier Solid Loading Rate (SLR)

- Lbs per day of solids in the clarifier influent per ft² of surface area

$$\text{SLR, lbs/d/ft}^2 = \frac{\text{Solids, lbs/day}}{\text{Surface Area, ft}^2}$$



Same Calculations as for
Hydraulic Loading

$$SA = L \times W$$

$$SA = \pi r^2$$

The Pound Equation for Solids


$$\text{Pounds} = \text{Conc.} \times \text{Flow (or Volume)} \times 8.34 \text{ Lbs/gallon}$$

Concentration Of Solids In the Water	X	Quantity Of Water The Particles Are In	X	Weight Of The Water
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The “Pound Equation” for Solid Calculations

$$\text{Pounds} = \text{Conc.} \times \text{Flow (or Volume)} \times 8.34 \text{ Lbs/gallon}$$

- Flow & volume should be in MG
- Concentration of solids must be in ppm (parts per million)
- If Flow is in MGD, the result solid generation would be Lbs/day

$$\frac{\cancel{\text{Lbs.}}}{\cancel{\text{M Lbs.}}} \times \frac{\cancel{\text{M}} \text{ gal}}{\text{day}} \times \frac{\text{Lbs.}}{\cancel{\text{gal}}}$$


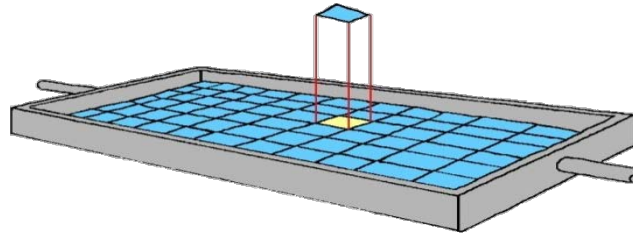
Clarifier Solid Loading

Solids Loading

- Solids Loading Rate (SLR)

The pounds per day of solids in the clarifier influent per square foot of surface area

$$\text{SLR, lbs/d/ft}^2 = \frac{\text{Solids, lbs/day}}{\text{Surface Area, ft}^2}$$



Typical Design Value = Max 30 lbs/d/ft²

Example for Clarifier Solid Loading Calculations

- Calculate the Solids Loading Rate for a clarifier with a 50 ft diameter and a depth of 12 feet, and receives a flow of 2.4 MGD with a suspended solids concentration of 1800 mg/L.

$$\text{SLR, lbs/d/ft}^2 = \frac{\text{Solids, lbs/day}}{\text{Surface Area, ft}^2}$$

$$\text{Solids, lbs/day} = 1800 \text{ mg/L} \times 2.4 \text{ MGD} \times 8.34 \text{ lbs/gal} = 36,029 \text{ lbs/d}$$

$$\text{SA} = 3.14 \times 25 \text{ ft} \times 25 \text{ ft} = 1962.5 \text{ ft}^2$$

$$\text{SLR, lbs/d/ft}^2 = \frac{36,029 \text{ lbs/day}}{1962.5 \text{ ft}^2} = 18.4 \text{ lbs/d/ft}^2$$

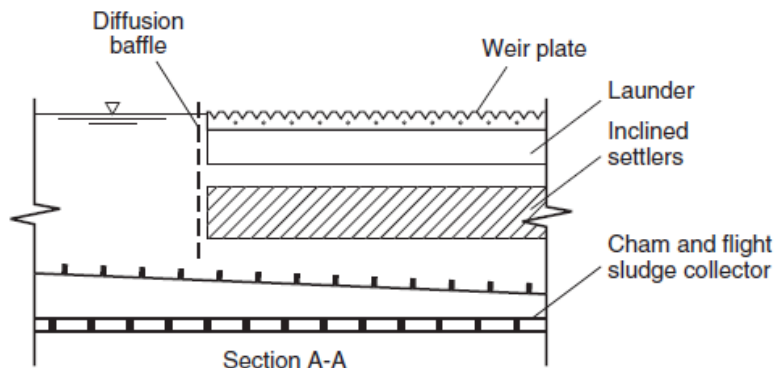
Sludge Collection for a Sed Basin

- Chain and flight
- Sludge scraper,
- Hose-less vacuum

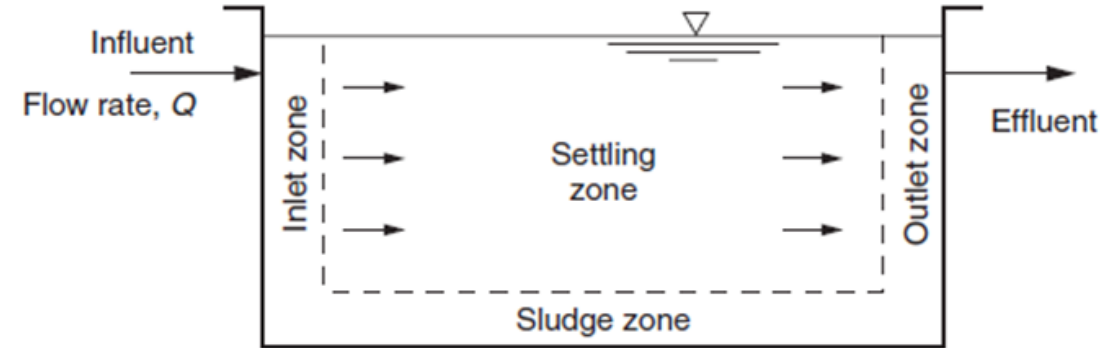


Weirs at a Sed. Basin

- The outlet zone (or Launder) should provide a smooth transition from the sed basin to the outlet without disturbing the flocs
- Weirs installed at the edge of sed basins
- Weirs is used to measure the flow rate
- Enough length of weirs should be provided
- 20,000 gal/day/ft is the rule of thumb

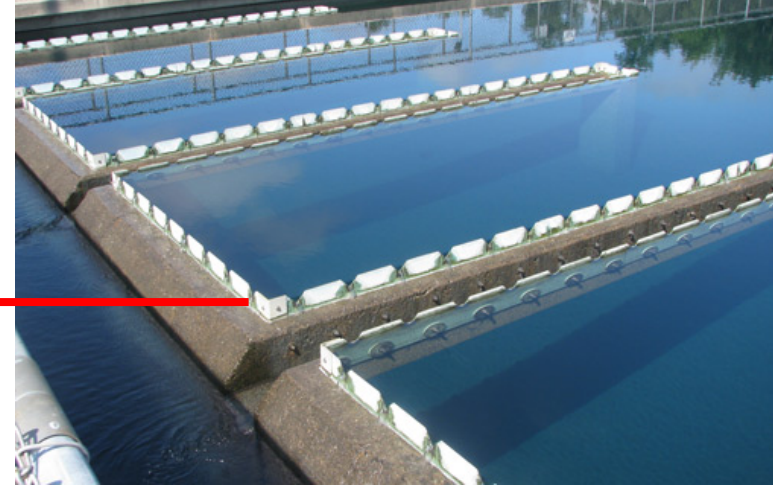
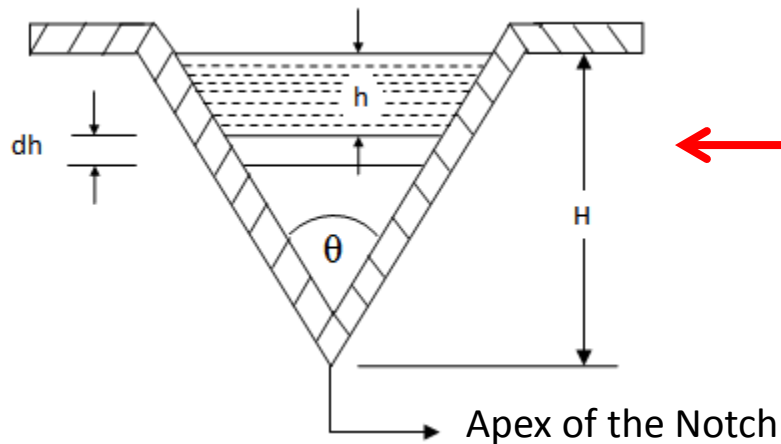


(b)



How does weirs work?

- Assuming Triangular Notch
- The outlet zone (or Launder) should



- H = Height of the liquid above the apex of the notch
- θ = Angle of the notch
- C_d = Coefficient of discharge

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan \frac{\theta}{2} \times H^{\frac{5}{2}}$$

Example for Weir Calculations

- A right Angle V-notch weir (Thomson Weir) was used to measure the discharge rate of a centrifugal pump. If the depth of water at V-notch is 200 mm, calculate the discharge rate over the notch in L/min; assuming coefficient of discharge is 0.62

Given,

- $\theta = 90^\circ$
- $H = 200 \text{ mm} = 0.2 \text{ m}$
- $C_d = 0.62$

We know that the discharge over the triangular notch,

$$Q = \frac{8}{15} C_d \sqrt{2g} \tan \frac{\theta}{2} \times H^{\frac{5}{2}}$$

$$\Rightarrow Q = \frac{8}{15} \times 0.62 \times \sqrt{2 \times 9.81} \tan 45^\circ \times (0.2)^{\frac{5}{2}}$$

$$\Rightarrow Q = 1.465 \times 0.018 = 0.026 \text{ m}^3/\text{s}$$

$$\therefore Q = 26 \text{ liter s/s} = 1560 \text{ liter s/min}$$

Advanced Sedimentation Technologies

- High-Rate Sedimentation Processes (Chapter 10-7)
 - Plate Settlers
 - Tube Settlers
- Very High-Rate Clarification Process
 - Ballasted Sedimentation (Actiflo)
 - Contact Clarifiers (Densadeg)
- Dissolved Air Floatation (DAF)

High-Rate Sedimentation/Clarification Processes

- Solids must reach the “Sludge Zone” to be removed
- High-Rate Clarification utilizes tubes or plates to enhance solid settling process

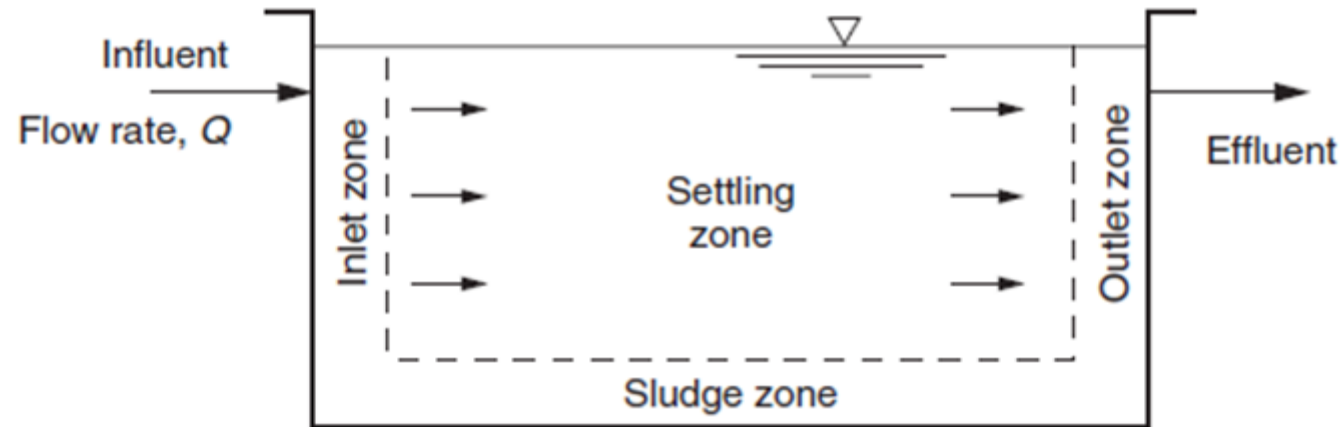
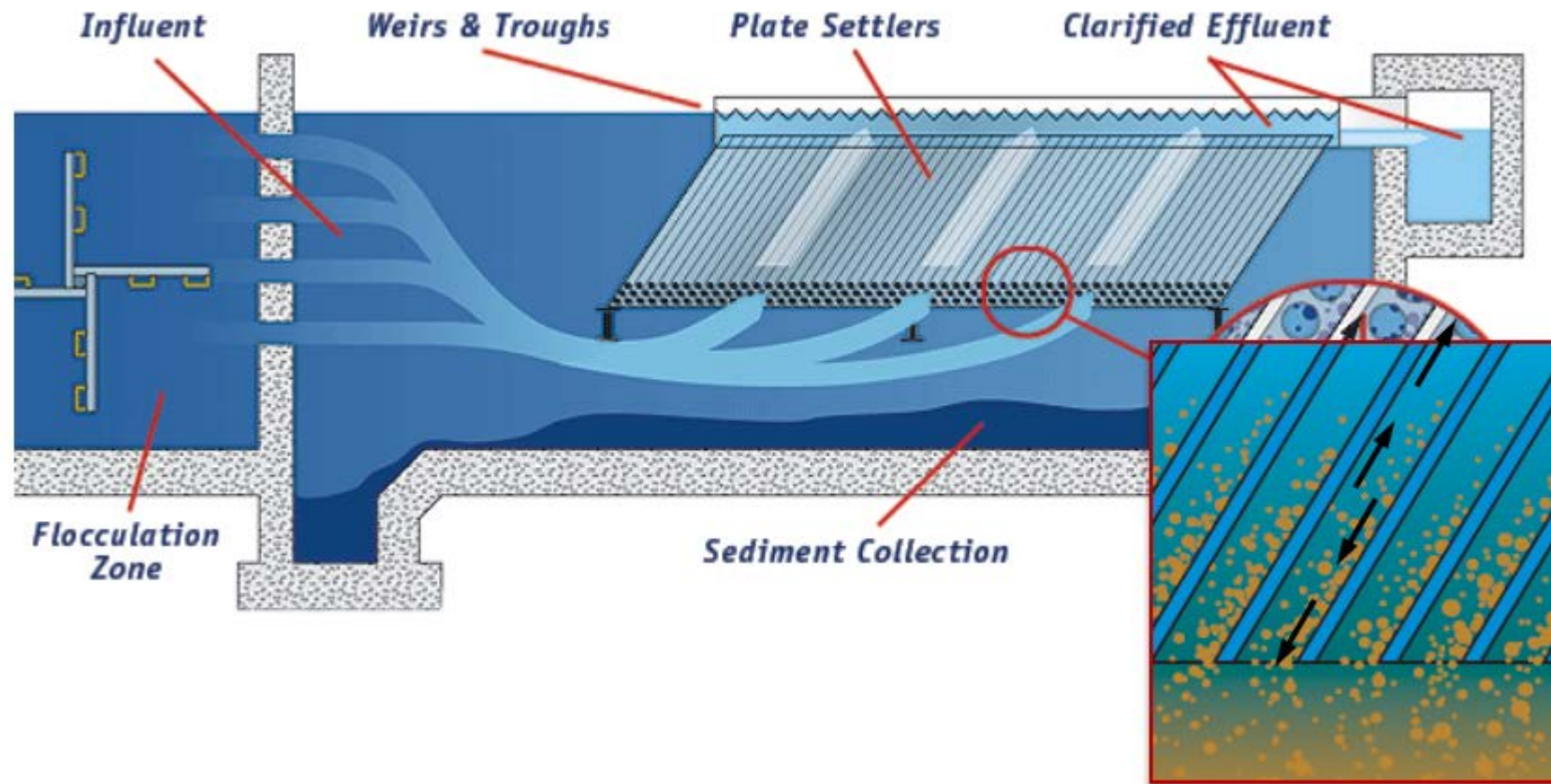


Plate Settlers

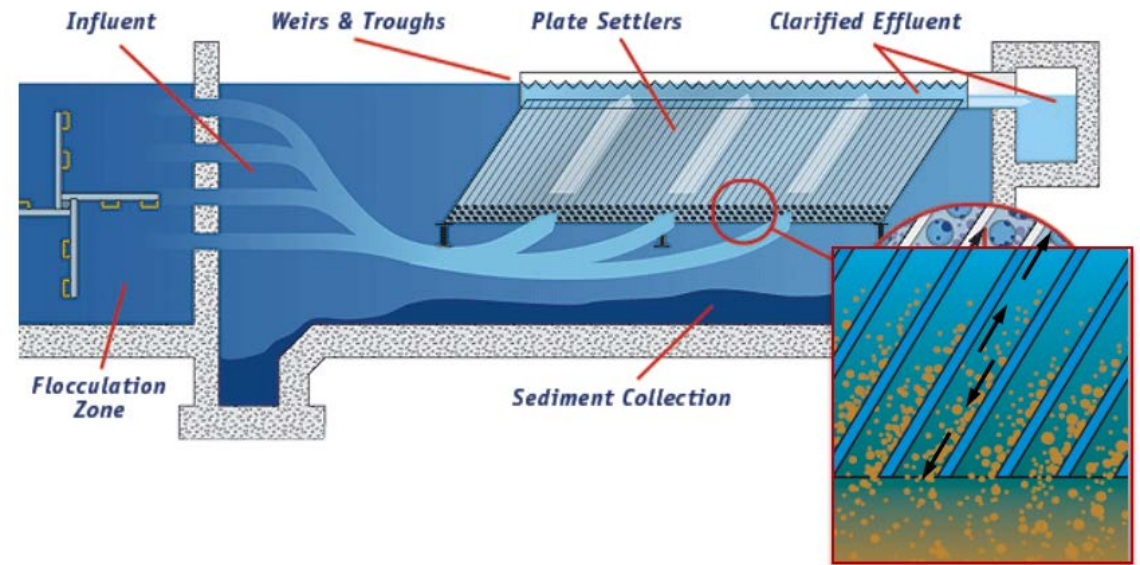
How does plate/tube settlers work?

- Plate/tube settlers offer large settling area in a small footprint



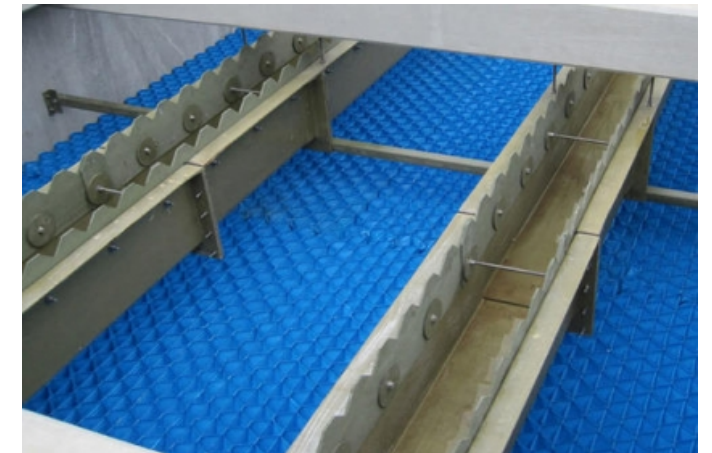
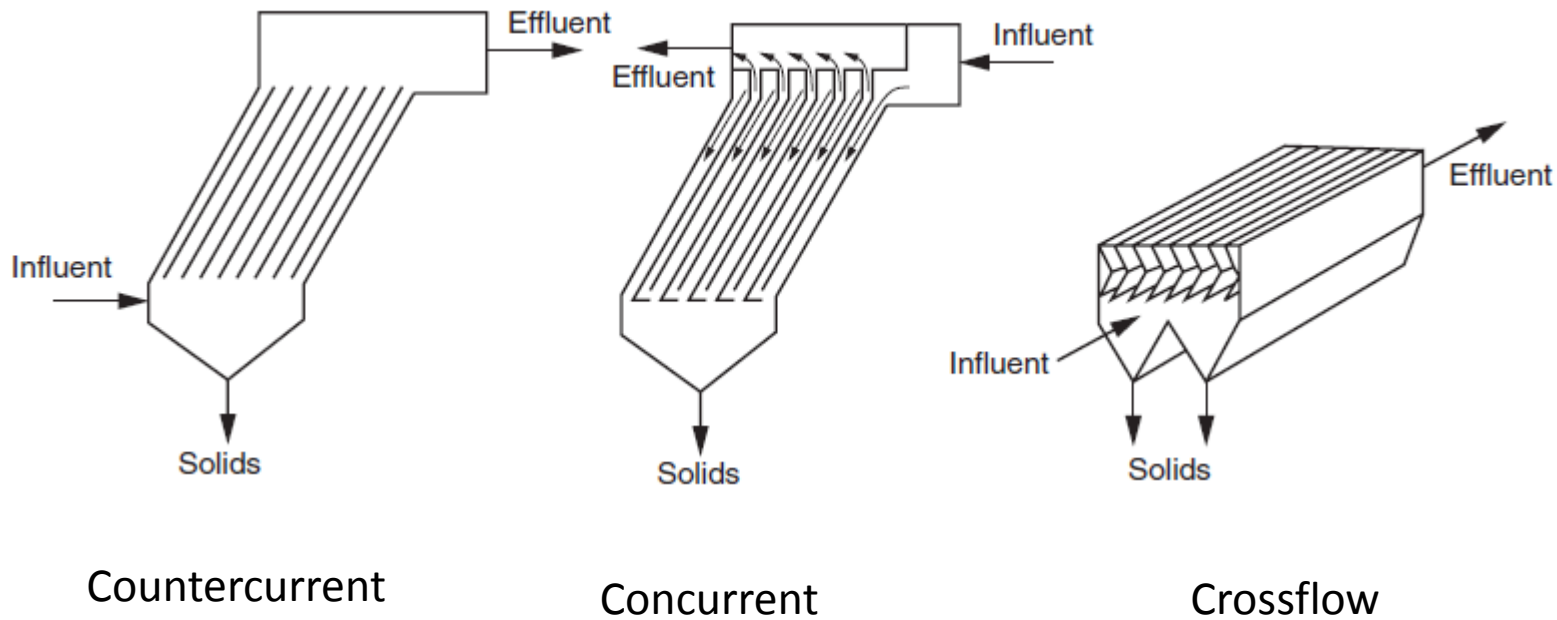
How does plate/tube settlers work?

- Processes that utilize tubes or plates to
 - Increase area of “sludge zone” on the surface of tubes or plates
 - Reduce the distance for particles to get to the “Sludge Zone”
 - Particles usually do not retain at the surface; but rather fall down to the bottom of the tank



Different Flow Patterns for Tube/Plate Settlers

- Countercurrent
- Concurrent
- Crossflow



Tube Settlers

Counter Current Plate Settler Calculation

The settling time for a particle to move between countercurrent parallel plates is given by the expression

$$t = \frac{d}{v_s \cos \theta} \quad (10-34)$$

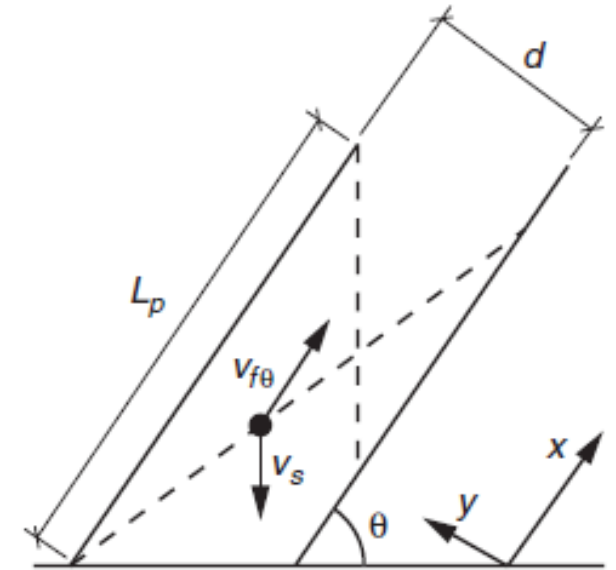
where

t = settling time, s

d = distance between two parallel plates (perpendicular to plates), m

v_s = particle settling velocity, m/s

θ = inclination angle of plates from horizon, deg



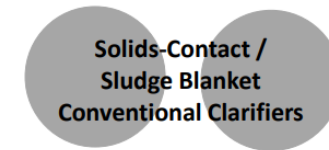
- Calculation for plate or tube settlers is well established and can be obtained from the manufacturers
- Countercurrent is often used especially when a larger angle ($>60^\circ$) is desired for a smaller foot-print application

Advantages of Plate/Tube Settlers

- Provides better settled water quality
- More reliable than conventional sed. basins
- Requires smaller footprint than conventional clarifiers
- Lower cost (in most cases)
- Usually requires less coagulant dosage
- Easier O&M
 - Sludge collection mechanism is the only moving part
 - Hosing down the sludge is fairly easy (~monthly)

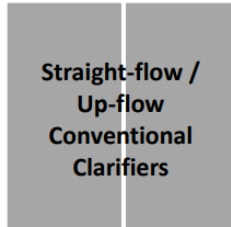


Plate
Settlers



Solids-Contact /
Sludge Blanket
Conventional Clarifiers

~3x the area of
plate settlers



Straight-flow /
Up-flow
Conventional
Clarifiers

~5x the area of
plate settlers

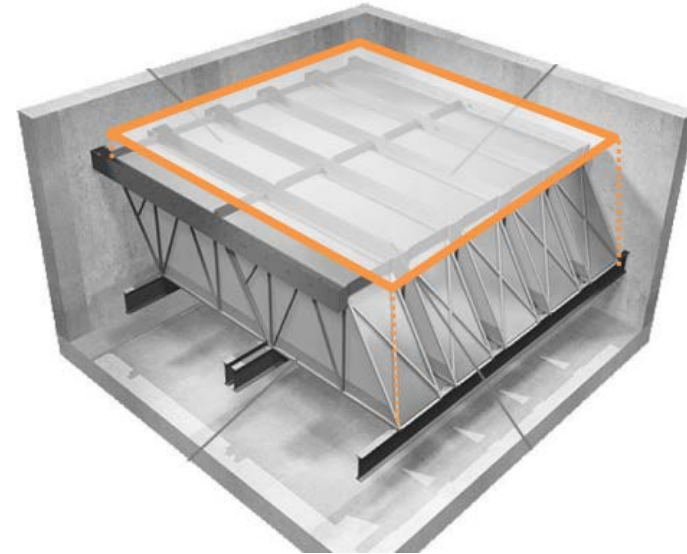
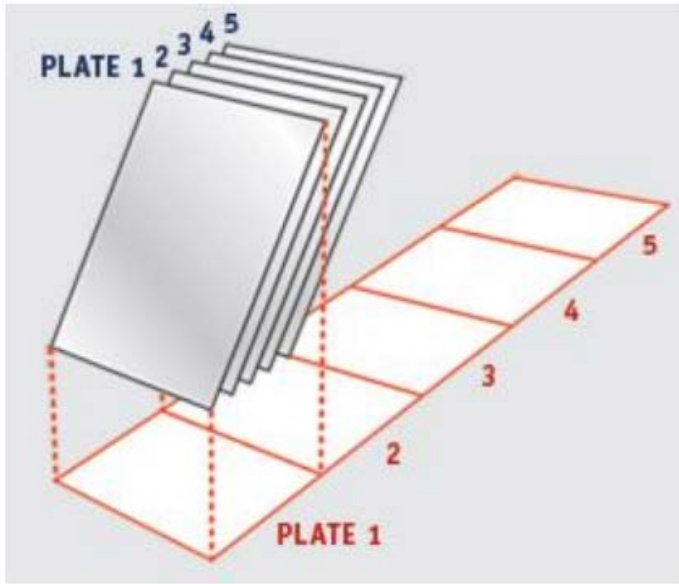
Capacity is Proportional to Horizontal Surface Area



$$\begin{array}{ccccc} \text{Capacity} & = & \text{Loading Rate} & \times & \text{Horizontal Surface Area} \\ \text{gpm} & & \text{gpm/sf} & & \text{sf} \end{array}$$

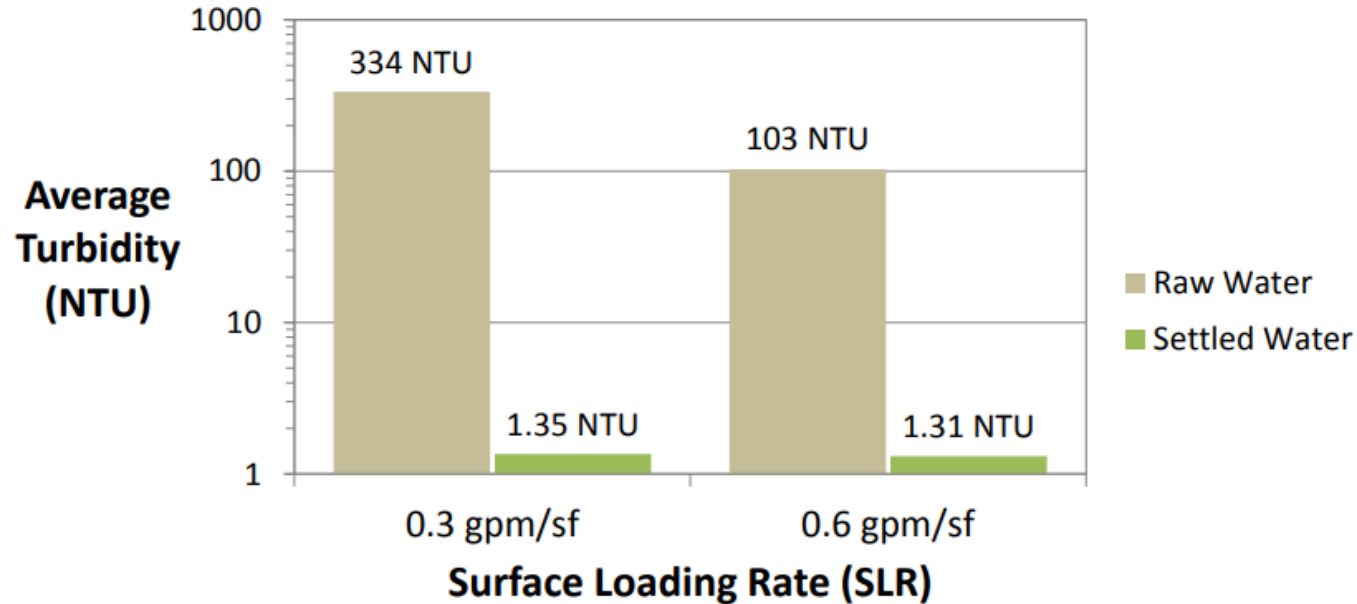
For Plate Settlers, Capacity is Based on Surface Loading Rate

- Surface Loading Rate (SLR) is calculated over vertically projected area
- Typically 0.3 – <1 gpm/sf for conventional sedimentation basins
- Plate/tube settlers could achieve ~ 3 gpm/sf
- Different SLR for different states and projects; pilot data usually required



Example from Missouri City Pilot Study

- Pilot data suggest increasing SLR from 0.3 gpm/ft² to 0.6 gpm/sf did not increase settled water turbidity
- Doubled the treatment capacity from 11 mgd to 22 mgd



Average Turbidity (NTU)		
Month	Raw Water	Settled Water
April 2013	33	0.70
May 2013	33	0.72
June 2013	43	0.75
July 2013	33	0.84

Tubes or Plates?

	Advantages	Disadvantages
Tube Settlers	<ul style="list-style-type: none">• Available in blocks; easily fitted into many different sizes and shapes of tanks and can be held in place by steel supports• Most of them are made in PVC so they are lightweight and economical	<ul style="list-style-type: none">• May experience flow distribution issue due to small flow path• Possible blocking• Easier to break• Broken pieces could move downstream to filters or membranes• Settling zone may interfere with incoming water
Plate Settlers	<ul style="list-style-type: none">• Constructed in stainless steel with high durability and longevity• Low maintenance• Mounted on stainless steel frames in a modular design for easy installation• Size of basin could be 2X less than that with tube settlers due to its high efficiency	<ul style="list-style-type: none">• Requires a certain height of building for installation (plant-specific design could be available from the manufacturers, such as shorter plate)• Initial cost could be higher; but could be offset by its longer service life

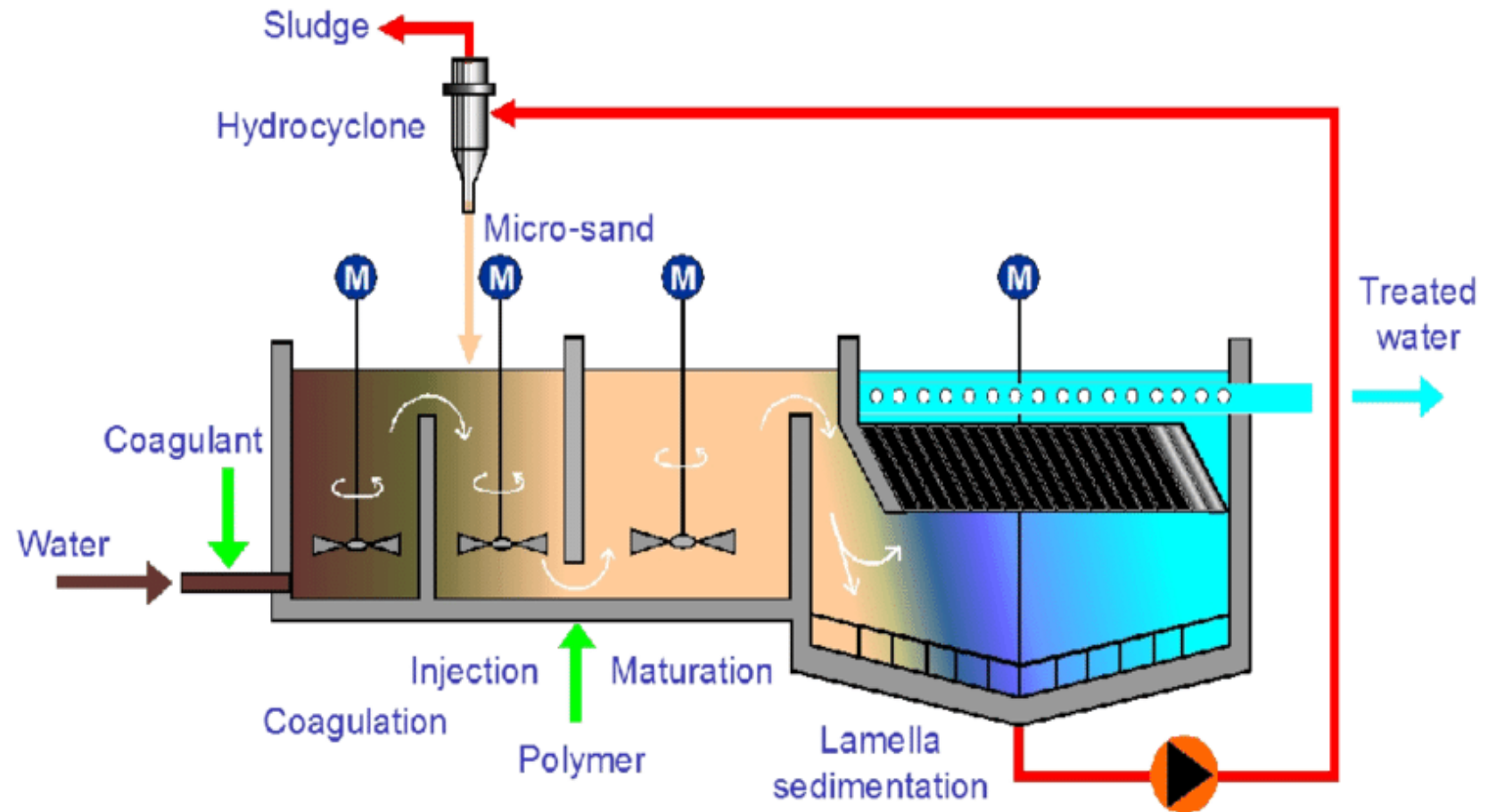
Very High Rate Clarification Process

- Increasing surface loading rate from $< 1 \text{ gpm/ft}^2$ to $> 30 \text{ gpm/ft}^2$
- High Rate Clarification is achieved via two main schemes
 - Reduce the distance that particles need to travel before they hit the “sludge zone”
 - Make particles heavier

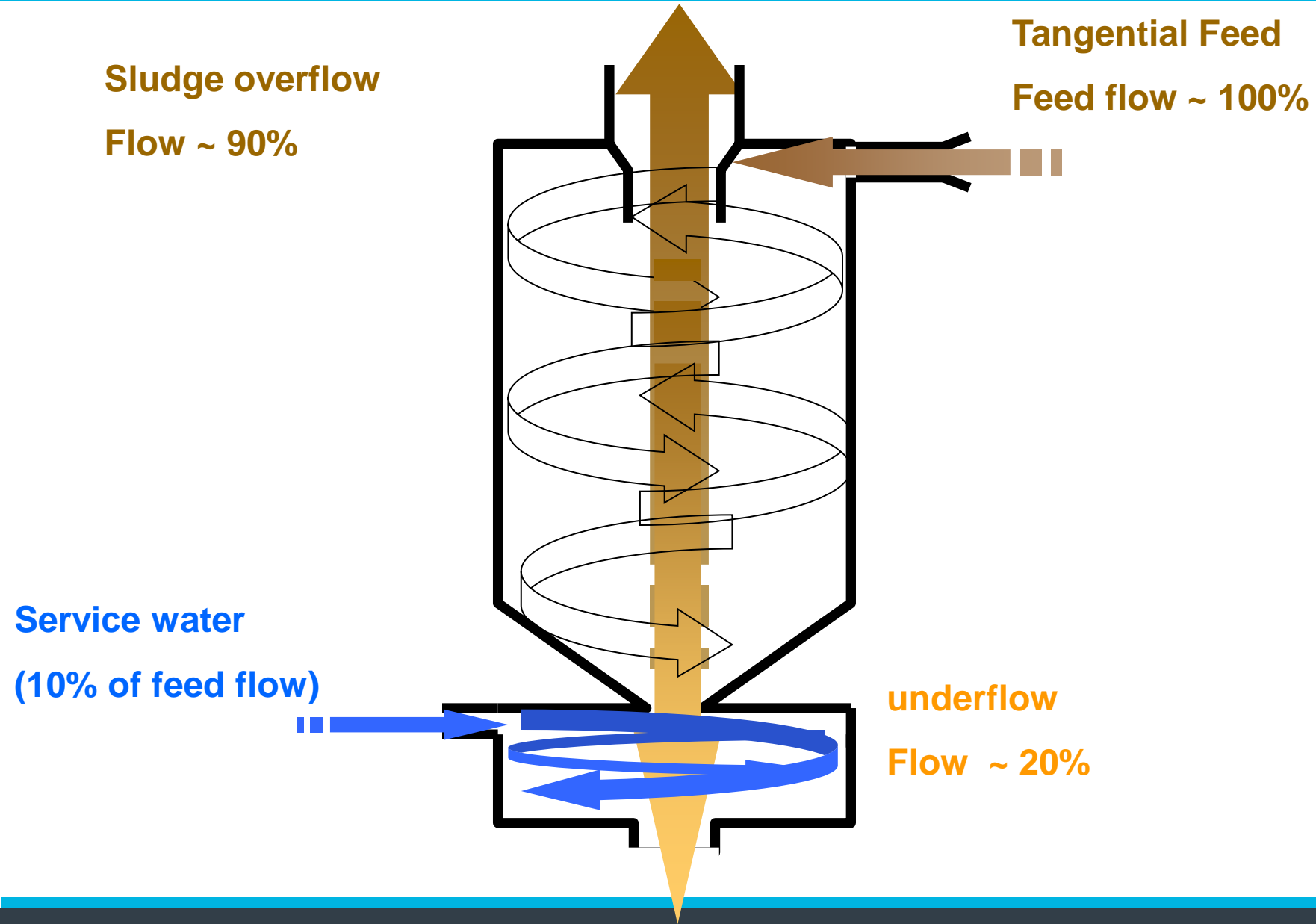
Surface Loading Rate: Quantity of water can be treated per minute per ft^2 of surface area of a treatment process tank. A higher surface loading rate translates to a lower surface area needed of a treatment process, which translate to lower construction costs. However, it is also considered a more “aggressive operation scheme” in the eyes of regulators.

Actiflo Process (by Kruger Veolia)

1. Coagulant added to the feed water
2. Flash mixing
3. Polymer and micro-sand addition
4. Maturation
5. Plate settler
6. Hydrocyclone for the separation of lighter flocs and heavy microsand
7. Return microsand

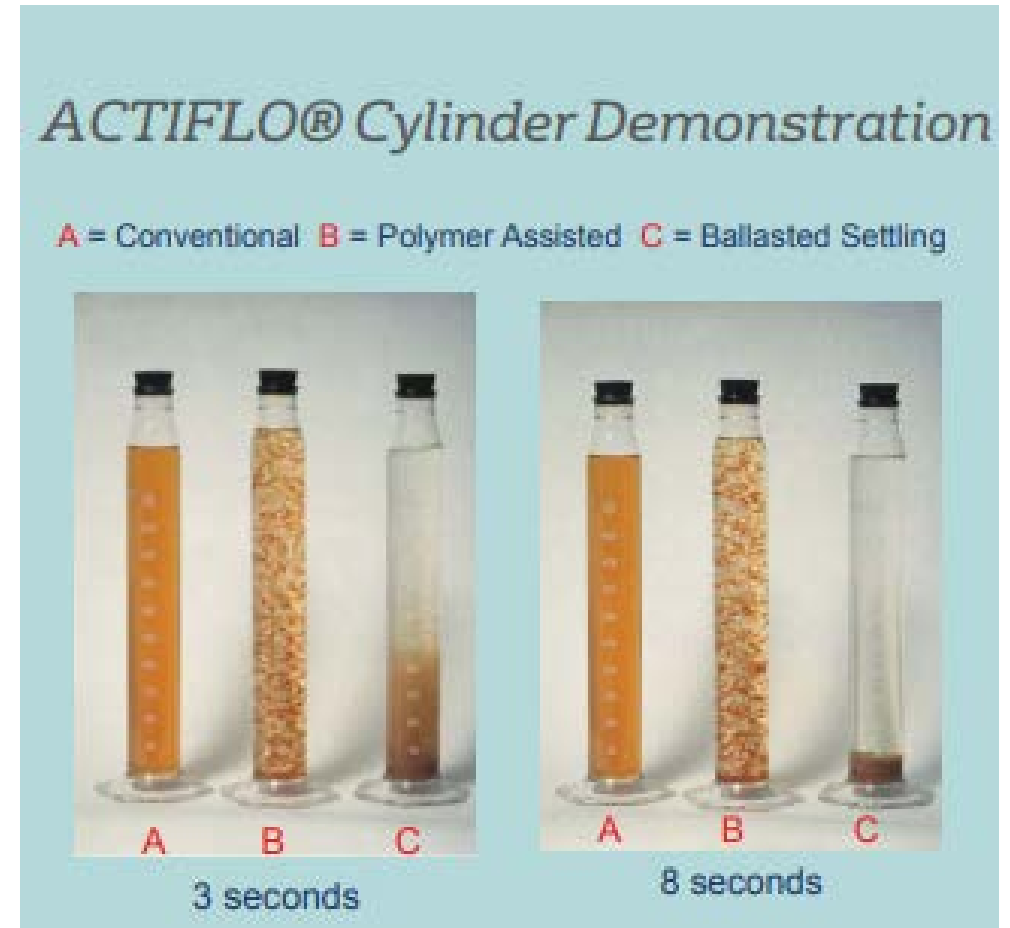


HydroCyclone



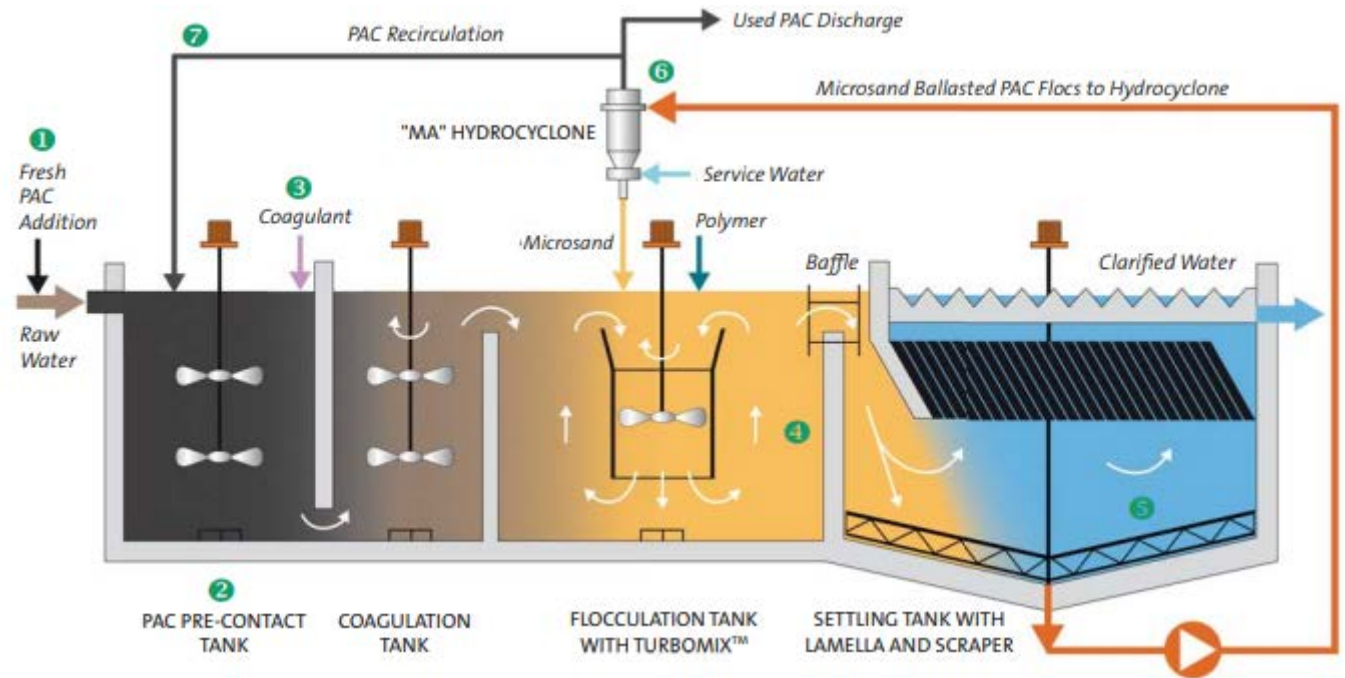
Benefits of Actiflo Process

- Very high clarification rate (> 30 gpm/ft²)
- Requires much smaller footprint (could be 10X smaller)
- Can handle rapid water quality change very well (optimization phase is pretty short; < 15 -20 minutes)
- Sometimes natural sand from the river can be used for sand replacement



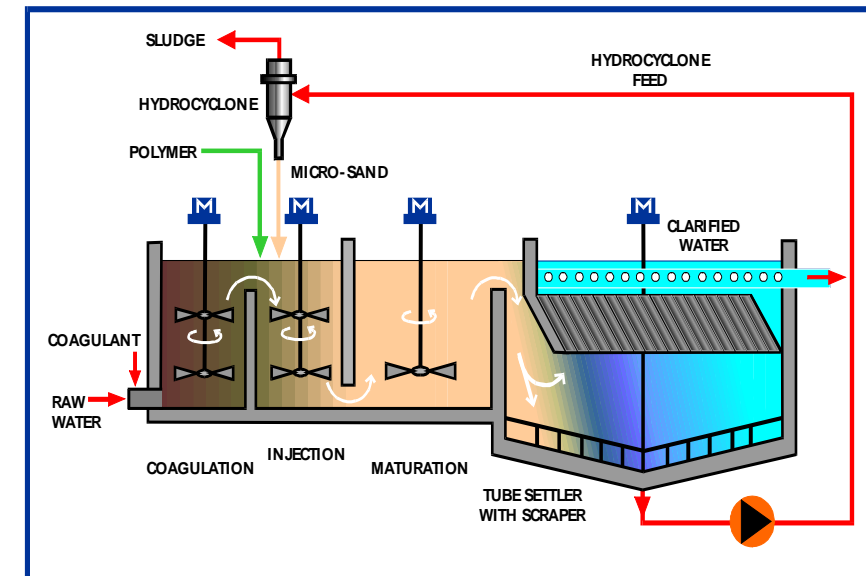
Actiflo Carb (by Kruger)

- Same concept and principles as Actiflo
- Powdered Activated Carbon (PAC) is added to the pre-contact tank for the removal of organic contaminants
- No polymer is used to avoid impact to PAC
- Most of the PAC is recycled



Potential Challenges for Actiflo

- Process depend on mechanical equipment
- Coagulant & polymer doses requirement is higher than conventional processes
- Excessive microsand carry over could happen during initial startup and commissioning
- There will be polymer and sand carry over; depending on dosing scheme
 - Could cause excess solid loading to downstream filters
 - Could cause filter media aggregation if polymer is over-fed
 - Could cause fouling and physical damage to downstream membrane processes



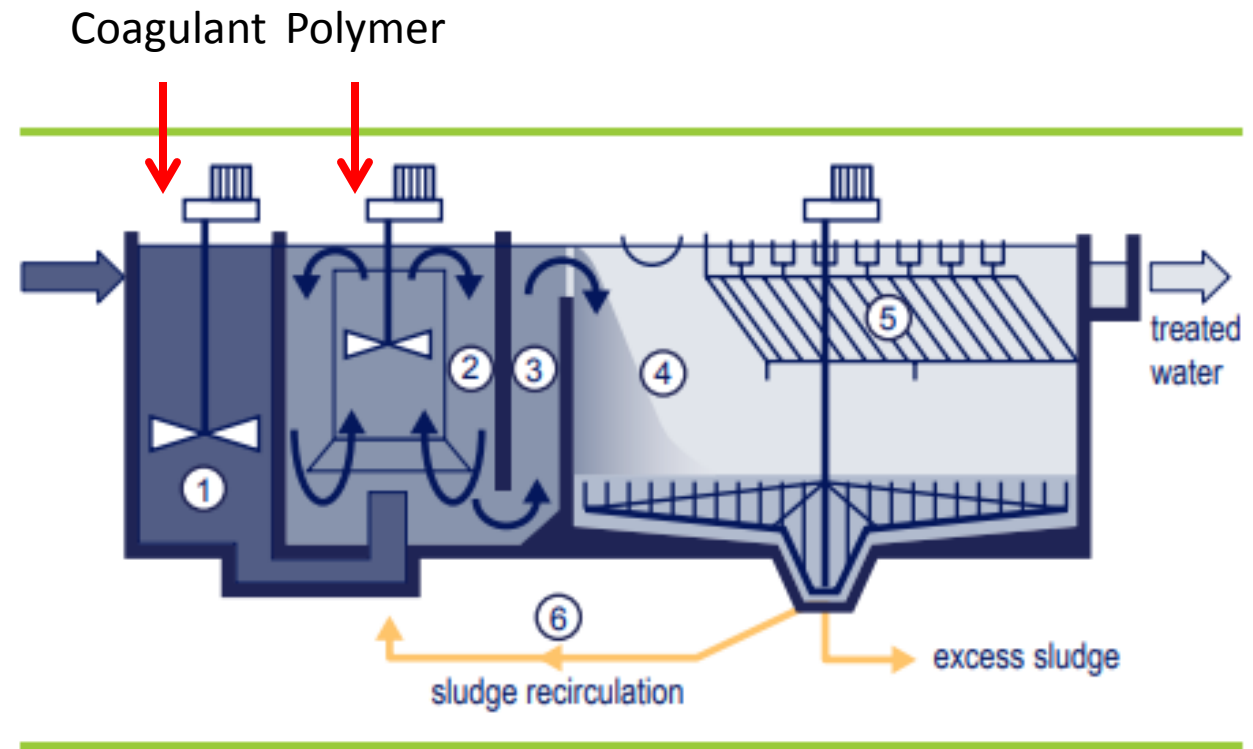
Densadeg

- A “Sludge Contact Clarifier”
- Can be used for drinking water, wastewater, industrial, and storm water
- Combines physical and chemical process to enhance settling rate
- Can produce higher concentration of solids (pre-thickening)



Working Principals for Densadeg

- Step 1: Flash Mixing
- Step 2: Flocculation & thickening (with sludge recirculation)
- Step 3: Transition to sed basin via an upward plug flow
- Step 4: Clarification with larger, denser particles settling down
- Step 5: Lamellar settlers used to settle smaller, less dense particles
- Step 6: Sludge thickening
- Step 7: Sludge to dewatering with partial sludge return



Considerations for Densadag

- Hydraulic Loading Rate: 10 – 15 gpm/ft²
- Could be more sensitive to water quality changes; thereby could experience transient operational challenges at time
- Could provide thicker sludge
- Not as widely used as Actiflo for drinking water treatment



Homework

Homework #1.

Calculate the Surface Loading Rate for a circular clarifier that has a diameter of 60 ft, and receives an influent flow of 1.65 MGD.

Homework #2.

Calculate the Solids Loading Rate for a clarifier with a 31 ft diameter and a depth of 9 feet, and receives a flow of 750,000 gallons per day with a suspended solids concentration of 2,600 mg/L.

Homework #3.

Problem 10-9 on Page 723. Hint: This problem is similar to Example 10 – 6 on Page 684

Homework Due 9/24