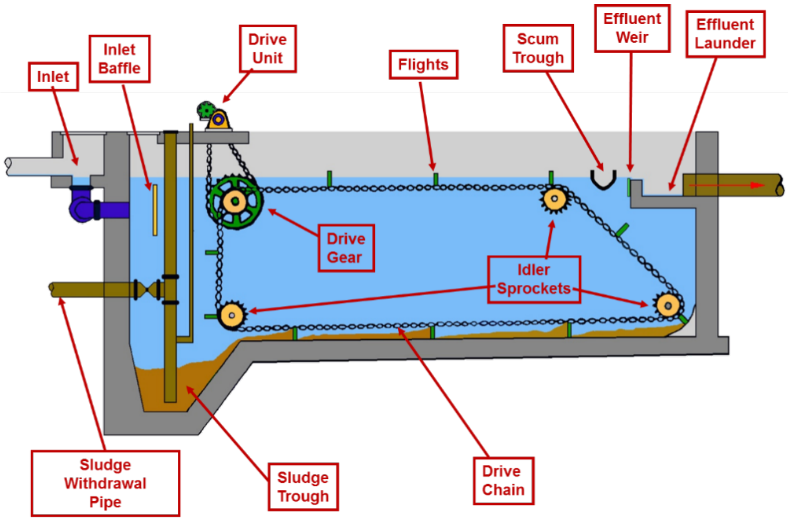
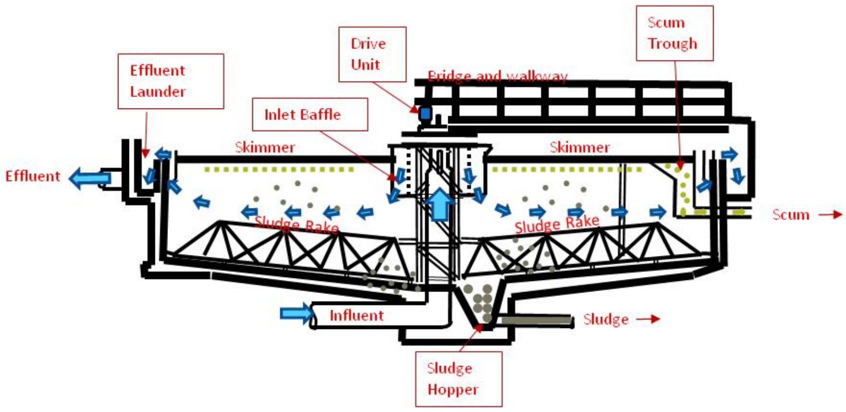
11. Primary Treatment

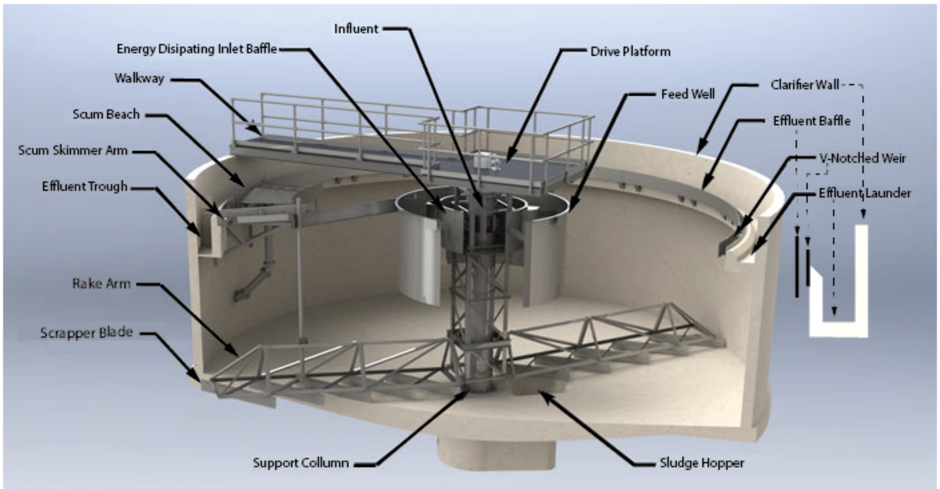
- Synonyms: primary treatment basin, primary clarifier, sedimentation basin, primaries, clarifier
- Primary treatment is after preliminary treatment and before secondary treatment
- Its two main objectives are:
  - Remove settleable solids
  - Remove floatable solids
- This is a physical process which relies on the physical properties - how heavy or light the suspended solids particles are to effect its separation
- Provides quiescent conditions for the influent wastewater for the heavier solids to settle and the lighter solids to float
- Removes settleable solids and floatables
- Settled solids are removed as sludge from the bottom of the clarifier
- Floatable solids including oil and grease are also removed, as scum from the surface
- The shape of the primary clarifier is either rectangular or circular
- Effective solids removal in the primary clarifiers will reduce the loading on the expensive secondary treatment process.
- The amount of solids removed during primary treatment may be enhanced by chemical addition - ferric or ferrous chloride as a coagulant and anionic polymer as the flocculant. This is called Chemically Enhanced Primary Treatment (CEPT).
- **Typical Removal Rates:**
  - BOD removal – 25% to 40% and about 60% with CEPT
  - Suspended solids (SS) removal – 40% to 60% and about 75% with CEPT
  - Settleable Solids removal - >90%



Cross section of a Rectangular Clarifier



Schematic cross section of a circular clarifier

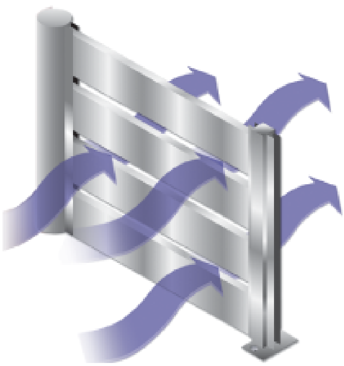


Cross section of a circular clarifier

11.1 Clarifier Zones

11.1.1 Inlet Zone

- Inlet Zone is where the water enters the end of a rectangular tank, or the center of a circular or square tank.
- The Inlet Zone is designed to accomplish two objectives:
  1. Reduce the velocity (dissipate energy in the incoming water)
  2. Distribute the flow evenly
- The inlet zone is equipped with a baffle. Inlet baffle reduces the velocity of the influent flow, prevent short circuiting which could cause solids being carried over to secondary treatment.
  - Circular tanks are equipped with a collar-type circular baffle that directs the water down as it enters the center of the tank.
  - Rectangular tanks will have a plate baffle in front of the opening for the wastewater flow into the clarifier and another baffle just upstream - a perforated wall or a picket fence type baffle that spreads the water laterally across the inlet end of the tank.



(a) Rectangular clarifier influent baffle

(b) Circular clarifier influent baffle

11.1.2 Settling Zone

- This is the largest portion of the tank where solids settle.
- The water velocity is reduced to 0.03-0.05 fps and the detention time is about 1.5 to 2 hours.
- A clarifier is said to be short circuiting if the velocity of the water is greater in some sections than in others. The water passing through the higher velocity region will have a reduced detention time and settleable solids will carry through with this water as it goes over the weir. Short circuiting is prevented by appropriately designing inlet baffles and weir plates (at the Outlet Zone).

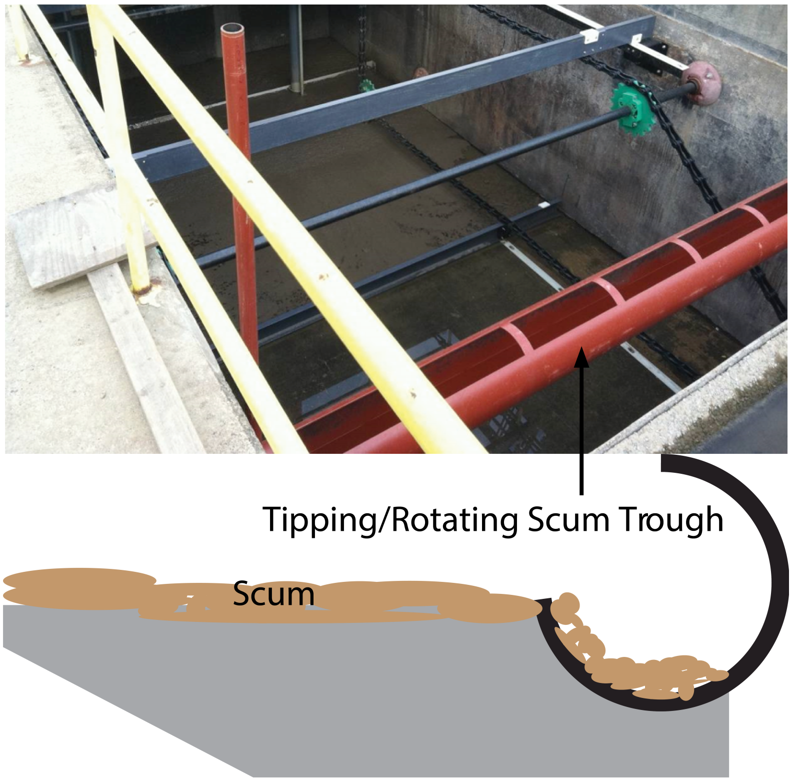
11.1.3 Sludge Zone

- Sludge zone is the bottom of the tank where the settled sludge collects and compacts.
- Sludge blanket depth should be measured and sludge should be removed at least every shift. A desirable blanket depth is typically established and the sludge pumping rate and regimen is established to maintain that desired sludge blanket level.
- Sludge rakes push the sludge to one end or the center of the tank so that it can be pumped out.
- The rake drive is usually equipped with a torque indicator. A shear pin in the drive shaft will break to prevent damage to the gearbox or drive shaft.
- Failure to remove sludge often enough will result in the sludge becoming septic releasing gas bubbles which hinders the sludge settling and also result in causing odor problems.
- The sludge from the primary clarifiers needs to be stabilized prior to its disposal. The sludge (solids) from the primary clarifiers are mixed with the solids from the secondary treatment process and stabilized typically using a sludge digestion process.

11.1.4 Skimming Zone

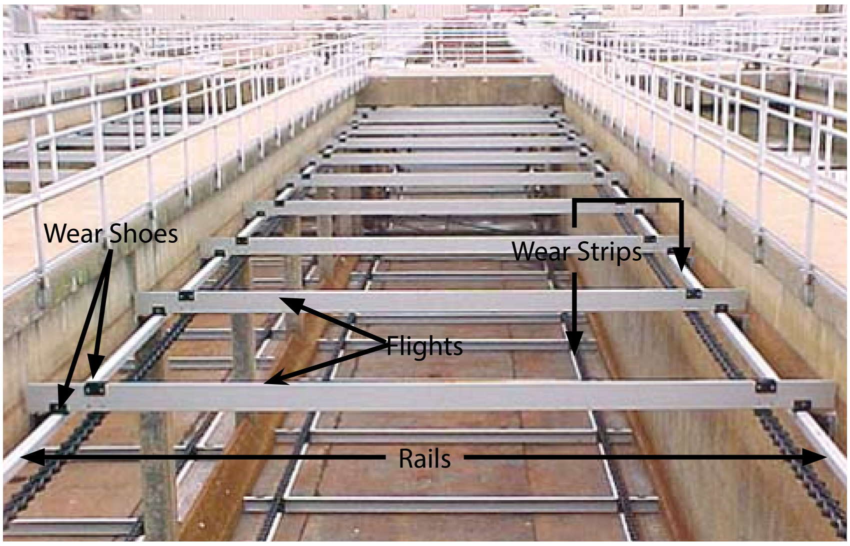
- The skimming zone is at the surface of the tank for scum removal
- Lighter solids and greases float to the surface of the clarifier as scum

- In Circular Clarifiers: Floating matter is skimmed by a skimmer arm that is supported by the sludge rake and rotates with it around the tank. The floating matter is pushed over the beach plate by the wipers attached to the skimmer arm and into a scum box attached to the tank wall.
- In Rectangular Clarifiers: The flights act as skimmers when the chain brings them to the surface and pushes the scum towards the scum troughs. The scum trough may be designed to rotate (tip) periodically for the scum to flow in from the water surface.
- The scum collected from the primary clarifiers is sent to the digester for treatment along with the sludge removed.



Rectangular clarifier scum trough

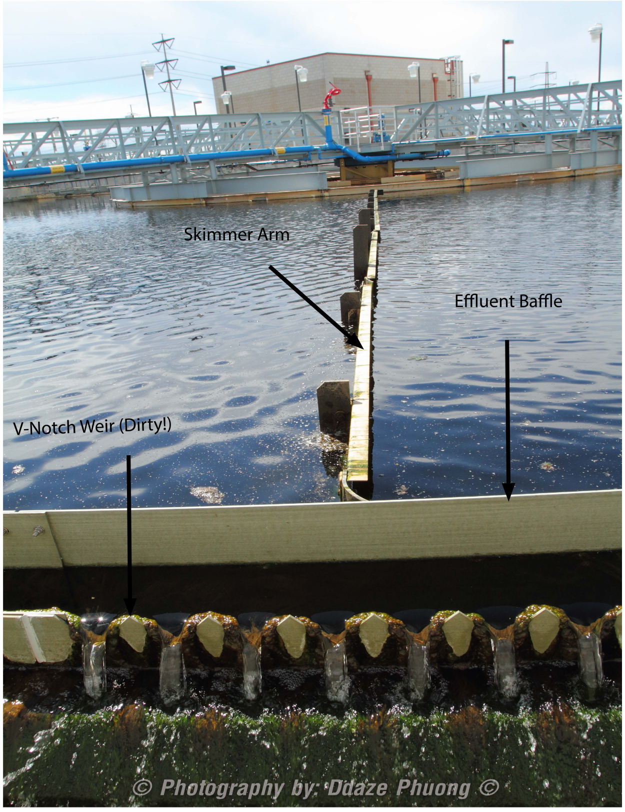
- The flights in the rectangular clarifier are supported at the top by two parallel rails running along the length of the clarifier.
- There are wear plates (strips) installed at the clarifer bottom and on top of the rails to prevent the flights from riding directly on those surfaces. To reduce friction, the flights have a wearing shoe attached.
- Both the wear strip and the wearing shoe are disposable items and are replaced at fixed intervals.



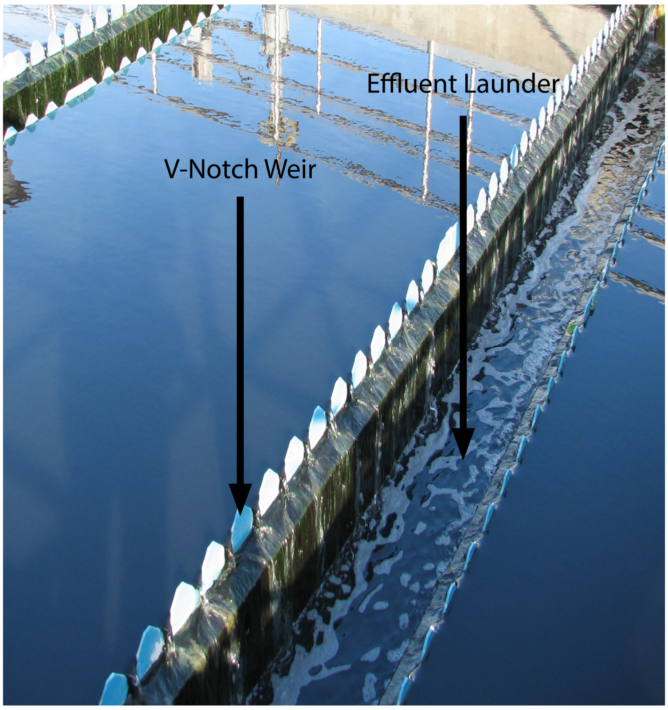
Rectangular clarifier flights

11.1.5 Outlet Zone

- This is the part of the clarifier where the settled water leaves to go to the secondary treatment processes.
- A channel called the effluent launder collects the effluent flow and directs it to the primary effluent piping.
- Weirs are installed along the edge of the effluent launder channel to skim the water evenly off the surface of the tank. The most common type of effluent weir is a V-notch (or saw-tooth) weir. A V- notch weir is a plate that has notches, about 2-3 inches deep, cut in it every 6-8 inches. If the weir is clean and level, it will remove water evenly all the way around the edge of the tank. This minimizes the upward velocities near the effluent launder and improves removal efficiencies. If the weir plate is not level or part of the weir becomes clogged with slime or debris, short-circuiting will result because more water will pass over the low side or the clean notches of the weir. Short-circuiting will cause poor settling and uneven sludge blanket buildup.
- In rectangular tanks the water leaves at the end opposite the influent.
- In circular tanks the water leaves at the edge of the tank.
- Also, in the circular clarifiers, an effluent baffle, just upstream of the weir, is installed to prevent floating solids from going over the weir.



Circular clarifier skimmer arm, effluent baffle and v-notch weir



Rectangular clarifier v-notch weir and launder

11.2 Sludge Pumping

- The sludge pumping from the clarifier must be adequate to prevent sludge from going septic. Septic sludges are much more difficult to thicken or de-water and cause odor issues.
- Primary sludge normally averages 4-6% solids. Generally positive displacement pumps are used for primary sludge
- The pumping cycles must be designed to provide the thickest sludge possible.
- Excessive pumping or pumping without building solids to build up leads to pumping thinner (more water) sludge.

11.3 Design Parameters

- **Clarifier depth** – 8 to 12 feet

- **Hydraulic or surface loading**
  - This rate is important to ensure good settleable solids removal efficiency
  - It is expressed in terms of gallons per day per square foot (gpd/sq ft) of tank surface area
  - Typical surface loading rate used for the design of primary clarifiers range between 300 to 1,400 gpd/sq ft, depending on the nature of the solids and the treatment requirements. Lower loading rates are frequently used in small plants in cold climates. In warm regions, low rates may cause excessive detention which could lead to septicity.

11.4 Advance primary treatment (APT)

Synonyms: Advance primary treatment (APT), Chemically enhanced primary treatment (CEPT), Physical-chemical treatment (Phys-chem)

11.4.1 Background

- Suspended solids present in wastewater are typically coated with bacterial slime and biological metabolic products which are negatively charged. A significant portion of the suspended solids in wastewater do not settle easily due to gravity as:
  1. the biological mass and the associated byproduct gases produced makes these particles buoyant,
  2. the negative electrostatic charges on these particles cause these particles to be in constant state of motion due to electrostatic repulsion
- involves chemical addition to the primary influent flow to enhance primary treatment TSS and BOD removal efficiencies
- a normal primary treatment process typically removes 40 to 60% TSS and 25 to 40% BOD. TSS and BOD removal efficiencies of over 80% and 60% respectively, may be achieved by the use of APT.
- additional cost incurred for the chemical addition is in most cases is offsetted by the benefits which include:
  1. by removing more BOD in the primary treatment cost associated with secondary treatment is reduced
  2. primary BOD is more easy to digest than the secondary biomass thus the digester gas production is increased and digested solids production is lowered thus saving biosolids hauling cost
  3. residual ferric chloride in the primary sludge provides H_2S and struvite control in the solids treatment processes

11.4.2 Process/mechanism

APT is a two step chemical process:

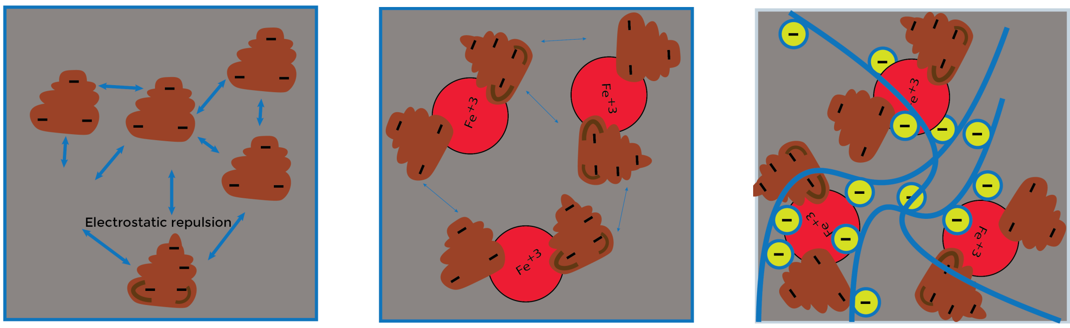
11.4.3 Coagulation

- Coagulation is the process by which the negative charge on these particles is reduced lowering the repulsion forces, by the use of a chemical such as ferric chloride and alum.
- The concentration of the coagulant required is dependent on the strength of the wastewater and the conveyance time of the wastewater.
- Typically the coagulant is added immediately after the grit chambers so the conveyance from the grit chambers to the primary clarifier provides adequate contact time and mixing.
- Parameters to ensure optimal coagulation are:
  - Appropriate coagulation concentration
  - Adequate mixing energy, and
  - Adequate contact time
- Overdosing the coagulant will adversely effect the settleability.
- Typical ferric chloride dosage for coagulation range from 12 to 22 mg/l.

11.4.4 Flocculation

- Flocculation uses an anionic polymer - polymer which has negatively charged groups, to bridge the coagulated particles to a size which will settle in the primary clarifier.
- The flocculated particles are prone to shearing thus the polymer is gently folded in with the coagulated wastewater just prior to entry into the primary clarifier

CEPT Schematic



Untreated Primary Inluent **Coagulation** **Flocculation**

11.5 Math Problems

Types of Math Problems Related to Primary Sedimentation

11.5.1 Hydraulic or Surface Loading Rate

The hydraulic or surface loading rate measures how rapidly wastewater moves through the primary clarifier. It is measured in terms of the number of gallons flowing each day through one square foot surface area of the clarifier.

$$Clarifier\ \ hydraulic\ \ loading\ \ \left(\frac{gpd}{ft^2}\right) = \frac{Clarifier\ \ influent\ \ flow(gpd)}{Clarifier\ \ surface\ \ area(ft^2)}$$

Rectangular clarifier surface area = width * length
Circular clarifier surface area = 0.785 * Diameter^2

11.5.2 Detention Time

Detention time is the length of time that wastewater stays in the settling tank is called the detention time. It is also the time it takes for a unit volume of wastewater to pass entirely through a primary clarifier

$$Clarifier\ \ detention\ \ time\ \ (hr) = \frac{Clarifier\ \ volume(cu.ft\ \ or\ \ gal)}{Influent\ \ flow\ \ (cu.ft\ \ or\ \ gal)/hr)}$$

Rectangular clarifier volume = width * length * depth of water
Circular clarifier volume = 0.785 * Diameter^2 * depth of water
Typically volume is calculated in cu. ft and influent flow is given in gallons. Use 7.48 gal/ft^3 conversion factor to convert volume in cu. ft to gallons.

11.5.3 Weir Overflow Rate

The weirs at the end of the primary clarifier allow for the even distribution of the the outlet flow across the entire length of the weir. An adequate length of weir is needed to ensure smooth and even flow of wastewater over the weirs. Weir overflow rate measures the number of gallons of wastewater per day flowing over one foot of weir.

$$Weir\ \ over\ \ flow\ \ rate\left(\frac{gpd}{ft}\right) = \left(\frac{Clarifier\ \ influent\ \ flow(gpd)}{Total\ \ effluent\ \ weir\ \ length\ \ (ft)}\right)$$

Circular clarifier weir length = 3.14 * Diameter
Example problem for (a), (b) and (c) above:

A circular clarifier receives a flow of 11 MGD. If the clarifier is 90 ft. in diameter and is 12 ft. deep, what is: a) the hydraulic/surface loading rate, b) clarifier detention time in hours, and c) weir overflow rate?

a) Hydraulic/surface loading rate:

$$Clarifier\ \ hydraulic\ \ loading\ \ \left(\frac{gpd}{ft^2}\right) == \frac{\frac{11\cancel{MG}}{day} * \frac{10^6 gal}{\cancel{MG}}}{0.785 * 90^2 ft^2} = \boxed{1,730 gpd/ft^2}$$

b) Clarifier detention time:

$$Clarifier\ \ detention\ \ time\ \ (hr) = \frac{Clarifier\ \ volume(cu.ft\ \ or\ \ gal)}{Influent\ \ flow\ \ (cu.ft\ \ or\ \ gal)/hr)}$$

$$Clarifier\ \ detention\ \ time\ \ (hr) = \frac{(0.785 * 90^2 * 12)\cancel{ft^3}}{\frac{11\cancel{MG}}{\cancel{day}} * \frac{10^6 \cancel{gal}}{\cancel{MG}} * \frac{\cancel{ft^3}}{7.48\cancel{gal}} * \frac{\cancel{day}}{24hrs}} = \boxed{1.2hrs}$$

c) Weir overflow rate:

$$Weir\ \ overflow\ \ rate\left(\frac{gpd}{ft}\right) = \frac{\frac{11\cancel{MG}}{day} * \frac{10^6 gal}{\cancel{MG}}}{3.14 * 90 ft} = \boxed{38,924 gpd/ft}$$

11.5.4 Removal Efficiency

Primary sedimentation removes suspended wastewater solids which includes BOD. The efficiency of the primary is established as the percentage of the amount of parameter removed. The parameter may quantified as mass (lbs) or as concentration (mg/l).

$$Removal\ \ efficiency(\%) = \frac{Parameter\ \ In - Parameter\ \ Out}{Parameter\ \ In} * 100$$

For TSS removal:

$$TSS\ \ Removal\ \ efficiency(\%) = \frac{TSS_{In}\ \ (mg/l) - TSS_{Out}\ \ (mg/l)}{TSS_{In}\ \ (mg/l)} * 100$$

For BOD removal:

$$BOD\ \ Removal\ \ efficiency(\%) = \frac{BOD_{In}\ \ (mg/l) - BOD_{Out}\ \ (mg/l)}{BOD_{In}\ \ (mg/l)} * 100$$

11.5.5 Solids Removal

Type 1 Problems: These involve calculating lbs of solids removed given any two of the following TSS parameters - inlet concentration, outlet concentration and removal efficiency.

a. If the inlet and outlet concentrations are given, calculate the mg/l of TSS removed using:

$$TSS_{removed} = TSS_{in}(mg/l) - TSS_{out}(mg/l)$$

Then knowing the flow, use the lbs formula to calculate the lbs solids removed.
b. If either inlet or outlet concentration is given along with the clarifier removal efficiency, using the removal efficiency calculate the unknown outlet concentration (if only the inlet is given) or the inlet concentration (if only the outlet is given)
i) If inlet and removal efficiency is given, calculate the outlet by subtracting the product of inlet and removal efficiency from the inlet.

$$TSS_{out} = TSS_{in} - (TSS_{in} * \%Removal)$$

Example if the removal efficiency is 60% and the inlet concentration is 300mg/l:

$$TSS_{out} = 300 - 300 * 0.6 = 120mg/l$$

ii) If outlet and removal efficiency is given, calculate the inlet concentration by dividing the outlet by (1-removal efficiency).

$$TSS_{in} = \frac{TSS_{out}}{1 - \%Removal}$$

Example if the removal efficiency is 60% and the outlet concentration is 120mg/l:

$$TSS_{in} = \frac{120}{1 - 0.6} = 300mg/l$$

Note: You may derive the above formulas by algebraically manipulating: $\%Removal = \frac{TSS_{in} - TSS_{out}}{TSS_{in}}$

Example Problem:
How many lbs of solids are removed daily by a primary clarifier treating a 6 MGD flow if the average influent TSS concentration is 300 mg/l and the clarifier TSS removal efficiency is 67%.
$TSS_{out} = (300mg/l - 300 * 0.67) = 99mg/l$
$lbs\ \ solids\ \ removed = (300 - 99)mg/l * 8.34 * 6MGD = \boxed{10,058\ \ lbs\ \ solids\ \ removed\ \ per\ \ day}$

Type 2 Problems: These involve calculating the amount of sludge pumping given the solids removed. The solids removed from the primary clarifier is sludge with a typical solids concentration of about 3% to 5%. Given the amount of total solids removed and given the sludge concentration, the volume of sludge pumping can be calculated as follows:

$$\frac{ft^3\ \ sludge\ \ pumped}{day} = \frac{lbs\ \ solids\ \ (removed)}{day} * \frac{1\ \ lb\ \ sludge}{(\%)\ \ lbs\ \ solids} * \frac{gal\ \ sludge}{8.34lb\ \ sludge} * \frac{ft^3\ \ sludge}{7.48\ \ gal}$$

So for the solids removed in the above example, if the primary sludge has 5% solids, the required sludge pumping can be calculated as:

$$\frac{ft^3\ \ sludge}{day} = \frac{10,058\ \ \cancel{lbs\ \ solids}}{day} * \frac{1\ \ \cancel{lb\ \ sludge}}{0.05\ \ \cancel{lbs\ \ solids}} * \frac{\cancel{gal\ \ sludge}}{8.34\cancel{lb\ \ sludge}} * \frac{ft^3\ \ sludge}{7.48\ \ \cancel{gal}} = \boxed{3,224\frac{ft^3\ \ sludge}{day}}$$