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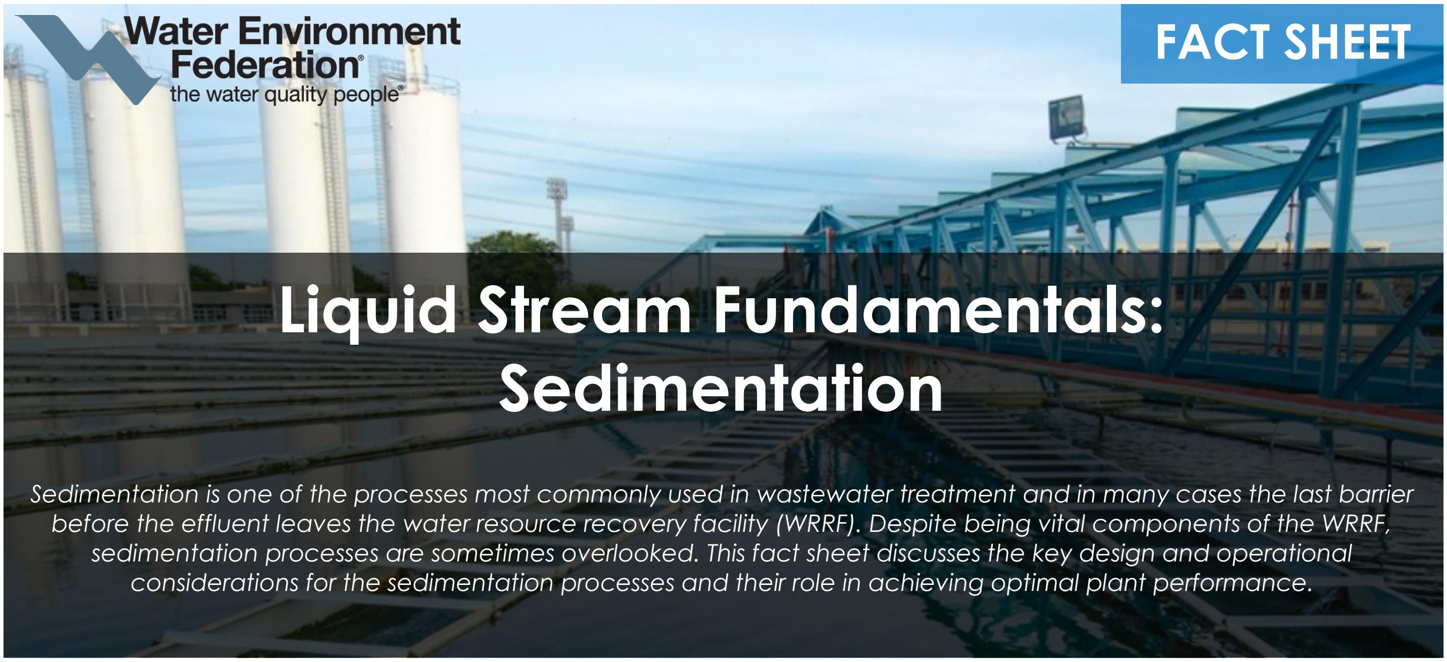

Liquid Stream Fundamentals: Sedimentation

Sedimentation is one of the processes most commonly used in wastewater treatment and in many cases the last barrier before the effluent leaves the water resource recovery facility (WRRF). Despite being vital components of the WRRF, sedimentation processes are sometimes overlooked. This fact sheet discusses the key design and operational considerations for the sedimentation processes and their role in achieving optimal plant performance.

Introduction

Sedimentation refers to the physical process where gravity forces account for the separation of solid particles that are heavier than water (specific gravity > 1.0). The common sedimentation unit processes in a wastewater liquid treatment train include grit removal, primary sedimentation, secondary sedimentation and tertiary sedimentation. This fact sheet primarily focusses on the primary and secondary sedimentation processes.

Tanks dedicated to primary sedimentation are typically referred to as primary sedimentation tanks, primary settling tanks or primary clarifiers. The tanks dedicated to secondary sedimentation are typically referred to as secondary sedimentation tanks, secondary settling tanks or secondary clarifiers. Within this factsheet these terms are used interchangeably.

Particles in sedimentation tanks/clarifiers settle in four distinct settling regimes basically dependent on the concentration of particles and their tendency to coalesce (Table 1).

Discrete Settling (Type I)	In this regime, particles settle as independent units with little interaction with neighboring particles. Discrete settling typically occurs for total suspended solids (TSS) concentrations less than 600 mg/L.
Flocculent Settling (Type II)	Flocculent settling typically occurs in the TSS range of 600 mg/L to 1,200 mg/L where particles start interacting with each other through collision and differential settling resulting in formation of larger particles through flocculation.
Hindered or Zone Settling (Type III)	Hindered or zone settling refers to settling where strong inter-particle forces result in formation of a matrix of particles that settle together. This settling regime is predominant at TSS concentrations typically between 1,200 mg/L and 5,000 mg/L.
Compression Settling (Type IV)	This type of settling is observed at very high solids concentrations where particles by means of their physical contact are able to compress the matrix releasing the water in between particles. This type of settling behavior is typically observed at TSS concentrations greater than 5,000 mg/L.

Table 1—Four Types of Settling Regimes

The dominant types of settling in a particular clarifier tend to depend on the type of influent (e.g. raw wastewater, mixed liquor suspended solids) and are also characteristic of certain regions within the clarifier (e.g. compression settling is dominant in the bottom region of the clarifier due to high solids concentrations). These regimes are discussed in further detail in the primary and secondary sedimentation sections.

Clarifier Functions

Generally, clarifiers in a wastewater treatment plant are designed to serve four main functions discussed below.

- Flocculation: Clarifiers should promote the aggregation of dispersed particles and prevent floc breakup.
- Clarification: Separation of solid and liquid fractions in the influent stream to produce a clarified effluent.
- Thickening: Production of thickened sludge streams.
- Storage: Clarifiers should be able to accumulate solids, particularly during storm events. In general, clarifiers should operate with low sludge blankets and the accumulation of solids should only occur during high flow periods.

The extent of each function/role performed by a clarifier is dependent on the type of unit process (primary, secondary, tertiary, etc.).

Primary Sedimentation

Primary sedimentation is one of the key processes for TSS and BOD removal in the liquid treatment train and for reducing the load to the downstream biological process (es). Primary sedimentation is principally governed by discrete settling (Type I) along with minimal flocculation/ flocculent (Type II) settling (Griborio et. al, 2014). Compression settling (Type IV) occurs in the sludge blanket region of the primary clarifiers. Settling in the primary clarifiers is targeted to maximize removal of the settleable fraction of the influent TSS and biochemical oxygen demand (BOD) (or chemical oxygen demand (COD)). Performance design goals for primary clarifiers are typically quantified based on TSS removal efficiency, which normally ranges between 50 and 75 percent, and BOD removal efficiency, which normally ranges between 25 and 40 percent (Tchobanoglous et. al, 2003). To maximize performance, the design of primary clarifiers must include features to promote flocculation and prevent hydraulic short-circuiting. Additionally, the design of primary clarifiers should include considerations for removal of floatables (scum).

Design Considerations

Design considerations for primary clarifiers can be divided into: 1) influent loading and wastewater characteristics-based design considerations, and 2) geometry-based considerations. This section discusses the design considerations based on influent loading and wastewater characteristics, while the geometry features of clarifiers are discussed in a later section.

Surface Overflow Rate (SOR)

SOR is defined as the rate of flow of clarifier effluent per unit of clarifier surface area and is theoretically the upflow rate that the settling solids in the clarifier need to overcome in order to settle before the liquid is carried out of the clarifier. Typical design SORs for primary clarifiers range from 800 to 1,200 gallons per day per square foot (gpd/sf) at average flow conditions and 2,000 to 3,000 gpd/sf at peak flows. Most state regulatory agencies specify limits for SORs, which may govern the design basis unless the design engineer provides a clear rationale for higher SOR loadings.

Primary Sludge Flow

Primary sludge removal rates generally should be optimized to provide high sludge solids concentrations, while avoiding any undesirable biological activity and resultant septic conditions. However, the optimum primary sludge solids concentration range will depend on downstream sludge handling facilities (e.g., pumping, thickening, degritting, fermentation, and/or digestion). Primary sludge concentrations are typically much higher than secondary sludge concentrations, resulting in higher effective viscosities that must be accounted for when selecting the scraper mechanism and sludge pumps.

Influent TSS

The extent of TSS/BOD removal achieved in primary clarifiers is dependent on primary influent characteristics, such as the ratio of non-settleable to settleable TSS, influent TSS concentration, settling characteristics of the settleable solids, soluble BOD/COD concentration and ratio of particulate BOD/COD to TSS. In general, primary clarifiers behave as solids equalization units where higher percent removals are achieved at higher influent TSS concentrations.

Temperature Effects

Temperature differences between the water in the tank and the primary influent can cause density currents to form. The rotational direction of the density current will tend to be counter-clockwise when cooler influent enters the tank and clockwise when warmer influent enters. The impact of these density currents should be taken into account when designing the clarifiers and appropriate considerations to reduce them should be analyzed, such as baffling, and appropriate sizing of the center well.

Chemically Enhanced Primary Treatment (CEPT) and High Rate Clarification (HRC) Processes

CEPT can be used to increase TSS and BOD/COD removals for primary clarifiers operating at typical SORs and to allow effective operation at higher SORs. CEPT processes seek not only to capture settleable suspended solids, but also a fraction of colloidal suspended solids.

Essentially, the use of chemicals (typically metal salts [i.e., ferric chloride or alum] and/or polymers) causes non-settleable solids to coagulate and flocculate with settleable solids, causing more solids to settle and at higher settling velocities. The basic CEPT process, while operating at average SORs for primary clarifiers, achieves TSS removals of 60 to 90 percent and BOD removals of 50 to 60 percent.

HRC processes include plate or tube settlers, ballasted flocculation processes, and solids contact/sludge recirculation clarifiers. These HRC processes allow operation at substantially higher SORs than conventional primary sedimentation by providing additional settling area in the same footprint (plate and tube settlers) and/or by using additional/other flocculent and settling aids, such as recycled solids or micro sand.

Secondary Sedimentation

The purpose of secondary clarifiers is to separate the incoming biomass from the biological reactors into clarified effluent and thickened sludge. For processes such as trickling filters and rotating biological contactors, the solids are typically settled and wasted, similar to primary sedimentation. For activated sludge, it is necessary to recycle most of the settled solids and return settled biomass back to the biological reactors to maintain a desired mixed liquor suspended solids (MLSS) concentration. The recycle stream is known as return activated sludge (RAS), while the fraction of sludge that is wasted and not recycled is referred to as waste activated sludge (WAS).

All settling regimes play a role in settling MLSS in the secondary clarifiers, basically depending upon the region of the clarifier. Type I settling is predominant in the upper region of the settling zone due to low solids concentrations, while Type II settling occurs in the inlet area (e.g., in the flocculating feed well of a circular clarifier) and in the region below the uppermost region of the settling zone where the concentration of solids is high enough for flocculation to occur. Further down in the tank (below the Type II region) is where Type III is predominant and the solids are carried to the sludge blanket. Type IV settling occurs in the sludge blanket (lowest region of the tank).

Design Considerations

Similar to primary clarifiers, design considerations for secondary clarifiers can also be divided into considerations based on influent loading and characteristics and those based on clarifier geometry. All of the design considerations noted below must be examined together, as all are critical in the design of the secondary clarifier system. This section discusses the design considerations based on influent loading and characteristics, while geometry features are discussed in a later section.

Surface Overflow Rate

SOR is a traditional parameters in secondary clarifier sizing and is commonly used to define the required clarifier surface area at average and peak flow conditions. The SOR typically ranges between 400 gpd/sf and 700 gpd/sf at average flow and between 800 gpd/sf and 1,600 gpd/sf at peak flow conditions (WEF MOP 8, 2005). Several state/local regulatory agencies may recommend limits on the maximum SORs that may be used in a clarifier design.

A commonly used design approach for secondary clarifiers is to define the clarifier area based on consideration of the SOR and the solids loading rates (considered below); but it is important to understand that typical design guidelines do not differentiate between the internal clarifier features and other influent loading characteristics that are decisive in the actual clarifier performance and capacity. Engineers should be cautious when applying design guidelines and should consider other processes and factors affecting secondary sedimentation.

Return Activated Sludge (RAS) Flow and Sludge Blanket Depth

RAS removal from secondary clarifiers used in activated sludge systems is typically done on a continuous flow basis to maintain the biological mass in the reactor basins and maintain a relative steady state condition in the clarifiers. Adequate RAS rates should be maintained to minimize denitrification in the sludge blankets, which can lead to reduced compression of the sludge blanket. Sizing of the RAS pumps should be adequate to ensure required sludge removal for blanket control at peak flow conditions. RAS pumps should also have the capability to operate at lower flow rates during average flow and diurnal low flow conditions. During clarifier operation, the ideal RAS rate is typically the lowest RAS rate that achieves the desired sludge blanket height (typically 1 to 3 ft). Using higher RAS rates than necessary creates unnecessary turbulence in the clarifier and dilutes the WAS, which results in higher WAS flows.

Mixed Liquor Suspended Solids (MLSS)

For activated sludge systems, MLSS concentration (which is a consequence of the sludge age) is one of the primary process control parameters. The MLSS concentration, together with the reactor volume, determines the amount of biomass available to accomplish biological treatment and must be high enough to satisfy treatment objectives. However, high MLSS concentrations can result in excessive solids loading rates (considered below) that adversely affect secondary clarifier performance. Therefore, it is imperative that the sizing of reactor basins and clarifiers be considered together to develop the optimum design.

Sludge Volume Index (SVI)

Sludge settleability is perhaps the single most important parameter affecting clarifier performance and capacity in activated sludge systems. The most common measurement for sludge settleability in activated sludge systems is the SVI, which is defined as volume occupied per unit weight of sludge after 30 minutes of settling and is typically expressed as milliliters per gram (mL/g) of sludge. While SVI is not a comprehensive indicator of sludge settleability, and it has been identified to have many pitfalls, it is still a useful and simple test routinely performed for activated sludge systems. A lower SVI indicates good settling sludge and vice versa. SVI values for good settling sludges typically range between 80 mL/g and 120 mL/g. SVIs higher than 140 mL/g typically hinder the ability of the sludge blanket to compact, limiting clarifier capacity. On the other hand, fast settling sludge with SVIs lower than 80 mL/g typically result in dispersed particles that are not incorporated into the settling suspension and high effluent TSS. When designing a clarifier, clarifier performance for the design flow and load conditions should be analyzed at different SVIs within the expected SVI range (which may be based on historical SVIs experienced at the facility).

Solids Loading Rate (SLR)

SLR is defined as the mass of solids applied per unit clarifier surface area per unit time and is typically expressed as pounds per day per square foot (lbs/d.sf). As described in the SOR section, clarifier design is commonly based on a consideration of the SOR and the SLR. The analysis of the allowable SLR, which typically governs the sizing of secondary clarifiers used in activated sludge systems, should be based on consideration of the sludge settleability.

The maximum allowable SLR is typically based on the limiting solids flux theory (i.e., the maximum amount of solids that can be conveyed to the bottom of the clarifier). Increasing the SLR above the limiting flux would result in thickening failure, blanket buildup, and, if continued long enough, solids washout from the clarifier. Typical maximum day design SLRs range from 25 to 45 lbs/d.sf., depending on the SVI. Higher SLRs could be used with low SVIs when adequate sludge removal, i.e., RAS capacity, is available.

Geometry Features

Geometry features of clarifiers can have a significant impact on clarifier performance and capacity and should therefore be carefully selected. This section discusses some of the main geometry features pertinent to both primary and secondary clarifiers.

Clarifier Configurations

Common geometric configurations for primary and secondary clarifiers are circular and rectangular. Other configurations such as square and octagonal clarifiers are also used but are far less typical. The choice of clarifier configuration depends on site specific space constraints, operator familiarity, maintenance requirements and the judgement of the engineer.

Circular Clarifier Configuration

Circular clarifiers are generally distinguished based on their feed system as discussed below.

<u>Center feed:</u> Center feed clarifiers are the most common configuration. In this case, the influent is fed through a center column to a center feed well. Center feed clarifiers are typically designed with a peripheral effluent overflow [Figure 1].

Figure 1— Circular Center Feed Clarifier with Peripheral Overflow (Broward County NRWWTP, FL)

<u>Peripheral feed systems:</u> These systems allow for feeding mixed liquor to the clarifier from the periphery of the clarifier; i.e., via a skirt or channel around the clarifier wall. Peripheral feed is used only in secondary clarifiers. Peripheral feed clarifiers can be designed with peripheral overflow effluent launders or, in the case of small clarifiers, with effluent launders located close to the center of the clarifier [Figure 2].

Figure 2— Circular Peripheral Feed Clarifier with Peripheral Overflow (East Bay MUD, CA)

Rectangular Clarifier Configuration

Rectangular clarifiers are typically classified based on the location of the sludge hopper in the clarifier. The sludge hopper can be located at the inlet end, outlet end (referred as Gould Type I clarifiers) or near the middle of the clarifiers (Gould Type II clarifiers).

Figure 3— Rectangular Clarifier Configuration (PWD Southwest WPCP, PA)

Figure 4— Octagonal Clarifier Configuration (Dry Creek WWTP, KY)

Sidewater Depth

Sidewater depth is governed by the distance desired between the effluent weirs and the sludge blanket. Adequate sidewater depths are needed to prevent sludge blanket solids from entering the effluent launder. While deeper clarifiers are likely to improve effluent quality (especially for secondary clarifiers), the extent of improvement should be weighed against the cost of construction to decide on the optimum depth. Typical sidewater depths for primary clarifiers range between 12 to 14 ft and from 14 to 16 ft for secondary clarifiers. Deeper clarifiers can be justified based on required performance and capacity.

In circular clarifiers, the sidewater depth should be evaluated in conjunction with the clarifier slope and center depth; sloping-bottom clarifiers have additional volume for accumulation of solids and can typically be designed with shallow sidewater depths compared to flat-bottom clarifiers.

Center Well

This geometric feature of the clarifier (also referred as feed well) is specific to circular clarifiers. The center well plays a significant role in promoting flocculation and improving tank hydrodynamics by helping to reduce the impact of density currents. Center well diameters for center feed circular clarifiers are typically 15% to 25% of the tank diameter for primary clarifiers and 20% to 30% of the tank diameter for secondary clarifiers. The top of the center well should be designed to be above the maximum water surface level as to direct MLSS flow under the center well and prevent short-circuiting of the MLSS to the effluent launder. The center well depth is typically 30% to 50% of the clarifier sidewater depth.

Energy Dissipating Inlet (EDI)

An EDI is a baffled area between the center column and the center well of center feed circular clarifiers. The purpose of an EDI is to dissipate the hydraulic energy of the influent flow as it leaves the center column and distribute the flow smoothly and evenly to the center well. EDIs typically promote passive flocculation by providing areas of flow impingement. EDIs, especially EDI outlet features, are generally specific to the vendors supplying them.

Sludge Collection

Effective sludge collection with minimal blanket disruption is a key component of clarifier design. Some of the commonly used mechanisms for circular and rectangular clarifiers are discussed in Table 2 and Table 3.

Baffling

Baffling is used in both primary and secondary clarifiers to dissipate energy, promote flocculation, prevent scum from entering effluent launders, and mitigate density currents and other currents that could impair clarifier performance.

Baffling in Circular Clarifiers

EDIs and center wells are used in circular clarifiers as previously discussed. Scum baffles are provided above and just below the water surface in front of effluent weirs to prevent scum carryover in the clarifier effluent. Additional baffles are frequently used to mitigate density currents and prevent solids from the sludge blanket from rising up the sidewall of the clarifier, as described below:

Peripheral/Stamford Baffles: Peripheral baffles are installed at the clarifier wall below the effluent launder or attached to the effluent launder and are inclined downward (typically at 45 degrees) toward the center of the clarifier. These baffles are commonly used in secondary clarifiers and sometimes used in primary clarifiers.

Crosby/Mid-Radius Baffles: These baffles extend from the bottom of the tank to the middle of the water depth and

Type of Sludge Collection Mechanism (Circular Clarifiers)	Description
Scrapers  *Irwin Creek WWTP, NC*	Scrapers are commonly used sludge removal mechanisms consisting of either multiple straight scraper blades or a curved blade referred as spiral scraper. Scrapers help to direct the sludge to the center of the clarifier as the mechanism rotates.
Suction Pipe  *South Central Regional Water Treatment and Disposal Board, FL*	This sludge removal mechanism consists of a series of suction pipes attached to a rotating arm. Each pipe draws sludge from the clarifier floor and discharges it into a sludge collection box at the top of the clarifier. The flow is produced by differential head between the clarifier liquid level and the liquid level in the sludge collection box.
Suction Header  *F. Wayne WRC, GA*	Suction headers are tapered suction pipes with orifices, which are used to draw sludge from the clarifier floor by the suction created by the RAS pumps or by differential head between the clarifier and the RAS wet well.

Table 2— Circular Clarifier Sludge Collection Mechanisms

***Note:** Only scraper sludge removal is used in primary clarifiers, while all three mechanisms are commonly used in secondary clarifier applications.*

Type of Sludge Collection Mechanism (Rectangular Clarifiers)	Description
Chains and Flights  *Noman M Cole PCP, VA*	This mechanism consists of flights connected to a conveyor type chain assembly. As the chains move, the flights at the bottom of the clarifier push the sludge toward the sludge hopper. For wide clarifiers, multiple hoppers are provided or another smaller chain and flight system referred to as the cross collector is used to move the sludge within the sludge hopper toward the discharge pipe. A screw type cross collector may be used instead of a chain and flight cross collector.
Reciprocating Rake  *Courtesy: WESTEC Inc.*	This mechanism consists of a series scraper blades attached to a common framework. The mechanism oscillates to transport the sludge toward the hopper during the forward motion and allows the sludge to slide over the blades during the backward motion.
Traveling Bridge  *Village Creek WWTP, AL*	Traveling bridge collectors have sludge scrapers or suction features suspended from a mechanism that moves back and forth along the length of the clarifier, removing sludge by suction, or pushing sludge to a hopper. These mechanisms are not typically used in new designs due to high construction and maintenance costs.
Floating Type Sludge Collector  *Clarksville WWTP, TN*	These mechanisms are similar to the traveling bridge devices and consist of sludge collection pipes running along the floor of the tank; but the pipe assembly is connected to a collection header mounted over floats. The complete floating assembly (connected to a drive/guide mechanism) traverses the length of the tank as the sludge is siphoned from the bottom of the tank into a collection trough.

Table 3— Rectangular Clarifier Sludge Collection Mechanisms

are typically located at the mid-radius position. These baffles are sometimes used in secondary clarifiers.

Baffling in Rectangular Clarifiers

Various types of baffles or diffuser assemblies are used to dissipate energy where flow enters rectangular clarifiers. These can include flat plate target baffles mounted 2 to 3 feet from the wall in front of the inlet ports or special inlet diffuser assemblies with two or more lateral outlet ports at each inlet location.

Additional full clarifier width baffles submerged several inches below the water surface (for passage of scum and floatables) and extending down to about mid-depth can be provided further out from the wall to form an inlet zone in which flocculation can occur. Baffles can be solid, perforated, or of the finger baffle (parallel vertical slats with openings between) design.

Full clarifier width baffles extending from near the floor to near the surface (between bottom and top chains and flights) with various opening patterns are sometimes used at one or more points along the length of the clarifier to dissipate density currents.

As described for circular clarifiers, scum baffles are provided above and just below the water surface in front of effluent weirs to prevent scum carryover in the clarifier effluent.

Scum Removal

Scum removal mechanisms are an important design feature for both primary and secondary clarifiers. In primary clarifiers scum consists primarily of fats, oils, grease and debris. Scum from secondary clarifiers can include biomass that has floated to the top (e.g., due to denitrification) and biological foam.

Circular Clarifier Scum Removal Mechanisms

Conventional skimmers are typically blades above and just below the water surface connected to the rotating sludge removal mechanism. The scum blade pushes the scum into a trough, typically located close to the effluent launder, for collection. There are also extended trough mechanisms that are similar to conventional skimmers, but the trough is larger and extends further along the radius of the clarifier.

Several other mechanisms such as ducking skimmers, rotating full trough and full trough are also used but mainly in secondary clarifier applications.

In circular clarifiers scum accumulations can also occur in the center well. Open ports along the top edge of the center well wall are typically provided to allow the scum to be carried radially outward, frequently assisted by water sprays, where it can be collected by the scum removal mechanism. Some clarifiers are provided with scum skimmers inside the center well.

Rectangular Clarifier Scum Removal Mechanisms

Rotating Scum Pipe: Chain and flight sludge collectors are typically fitted with a rotating scum pipe, which consists of a slotted (open top) pipe across the clarifier at the water surface to collect the scum pushed to it by flights traveling along the length of the clarifier at the water surface. Typically, the pipe is rotated periodically to allow the accumulated scum to flow into the slot for removal.

Power Skimmer: A power skimmer consists of a dedicated chain and flight collector, a scum beach, and a fixed trough to convey the scum. Flights physically push scum across the beach and into the trough for removal.

Spiral Skimmer: Spiral skimmers consist of revolving spiral shaped blades, a short scum beach, and a fixed trough. The blades push scum across the beach and into the trough where it is collected.

Effluent Launder

Effluent launders should be designed to minimize solids carry over in the effluent and minimize hydraulic disruption. Launders typically consist of troughs with v notch or square notch weir plates which should be carefully leveled to allow the flow to exit the clarifier in a distributed and even manner. The effluent troughs should be fitted with arrangements for draining the launders when the tank is drained or removed from service. It is critical that the design engineer account for flotation or support of the effluent launder should a clarifier be filled (buoyancy) or emptied (trough full of water). In addition to the trough-type launders, submerged suction pipes are also used for effluent collection but are not very common in the United States.

Different launder configurations for circular and rectangular clarifiers are discussed below:

Effluent Launder Configurations for Circular Clarifiers

Launder configurations for circular clarifiers include either inboard and outboard, depending on whether the effluent trough is constructed inside or outside the main tank wall, respectively. The troughs of the inboard launder may be constructed along the clarifier wall with weir plates installed along the inner edge of the trough or may be offset from the clarifier wall (inset launder) with weir plates on both sides of the effluent trough. Inset launders must be located at adequate distance from the clarifier wall to avoid the entrainment of solids in the effluent due to high velocities and updraft of solids between the outer weir and the clarifier wall.

Effluent Launder Configurations for Rectangular Clarifiers

Rectangular clarifier launders are placed close to the effluent end of the clarifier. The launders can be longitudinal and/or lateral with weirs on one or both sides. The placement of the launders and weirs should take into account the hydraulic patterns caused by the clarifier end wall (referred to as the end wall effect) and the designer should avoid the use of single launders to minimize the impact of the end wall effect.

Irrespective of the launder type and configuration, selected provisions to provide accessibility to the weirs/suction pipes for routine maintenance and repairs should be included in the design.

Effluent Launder Covers

Effluent launder covers are commonly used in primary and secondary clarifier applications for odor management (primary clarifiers) and to prevent algae growth. Launder covers are very effective for the aforementioned purposes, however, they impose a barrier for visualization of the effluent quality in the effluent launder; and this is a limitation that should be considered before implementation.

Instrumentation

While clarifiers are not instrumentation-intensive unit processes, some instrumentation-based controls can be useful for regulating and monitoring clarifier performance. One of the most commonly used instrumentation devices are sludge blanket readers/trackers (e.g. light emitting analyzers, ultrasonic analyzers, optical sensors). Sludge blanket measurement devices are mostly used in secondary clarifiers but could also be used in primary clarifier applications.

Instrumentation devices for monitoring clarifier drive torque, power and motion, which are used for protection of the clarifier drive gearbox and sludge collection mechanism, are also a common in clarifier designs. Other instrumentation options for clarifiers include mixed liquor/influent/effluent flow meters, primary sludge flow meters, RAS and WAS flow meters, and TSS probes.

Operation and Maintenance

Operation and control of clarifiers can range from completely manual to completely automated. In either scenario, the key operator responsibilities for clarifier operation are controlling RAS/primary sludge flow rates to maintain clarifier blankets and prevent solids carryover in the effluent, especially during high flows. Additionally, attention should be paid to monitoring flows, influent TSS, effluent TSS, underflow (sludge) TSS, and SVI (when applicable).

Design Tools

Clarifier design is complex and the resources for design and evaluation range from design standards (such as the Ten State Standards, local, state and federal standards) and literature guidelines (WEF MOP 8, Metcalf and Eddy, etc.) to limiting solids flux theory and sophisticated mathematical models (computational fluid dynamics, CFD). Since design standards and some literature-based resources do not take into account important site-specific factors nor the internal features of the clarifiers, designing with such simplifications can lead to over or under designs. More detailed tools available to designers include state point analysis (based on the limiting solids flux theory) and 1 dimensional (1D), 2D and 3D CFD models. A summary of the comparison between the various modeling tools is discussed in Table 4.

Level	Strengths	Applications	Weaknesses
Limiting Solids Flux Theory (Example: State Point Analysis)	Simple	Zone settling (secondary clarifiers preliminary design and operational)	Ignores hydrodynamics, flocculation and internal configuration. Cannot predict effluent quality.
1D CFD	Computational speed	All types of settling including 2 phase flows (applicable to primary and secondary clarifiers)	Ignores hydrodynamics, flocculation and internal configuration.
2D CFD	Computational speed compared to 3D. Includes all major processes, factors and geometric considerations affecting clarifier performance and capacity.	All clarifiers where there is a dominant flow direction; dynamic simulations. Models such as 2Dc (McCorquodale et al., 2005) are available for design engineers.	Ignores lateral non-uniformity in solids and momentum.
3D CFD	Completeness of governing equations; high spatial resolution.	All clarifiers. Steady state simulations where a dominant flow direction cannot be assumed. Typically, 3D models are built using commercially available platforms such as ANSYS Fluent, Open FOAM, CFX and Flow-3D.	Long execution times; high level of expertise required.

Table 4— Comparison of Modeling Tools (Source: Adapted from McCorquadale, 2010)

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