WRF 4973 Fact Sheet: ID 1160

Strategy: Process Intensification

Clarifier Optimization

Performance of Two Parallel Secondary Clarifiers: without Baffle Modifications.
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Performance of Parallel Secondary Clarifier: with Baffle Modifications at 30% Higher Flow.
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This fact sheet addresses the strategies used to optimize the performance of primary sedimentation basins and secondary clarifiers.

Primary sedimentation basins/tanks (also called primary clarifiers) are used to remove particulates, mostly organic particles, from the raw or screened wastewater. Removing organics reduces the load to the activated sludge biological nutrient removal (BNR) process. This reduction in organic biochemical oxygen demand (BOD) load will reduce the biomass production, reduce basin size, and reduce aeration requirements. However, the lower BOD load may be detrimental to the BNR processes that require soluble organics, for example enhanced biological phosphorus removal (EBPR) and nitrogen (N) removal (denitrification). Improved total suspended solids (TSS) and BOD removal in the primary sedimentation basin also diverts more organics to anaerobic digestion, which results in increased gas production and potential energy recovery. The improved organic load to the BNR process would allow for a higher solids retention time (SRT) operation or increased hydraulic capacity.

Primary sedimentation basin performance can be optimized with respect to TSS and BOD removal using various strategies. These strategies include adding chemicals for chemically enhanced primary treatment (CEPT) and improving flocculation and internal flow regime in the primary sedimentation basin by using baffles strategically located throughout the sedimentation basin to improve solids removal under average and high flows, among other strategies.

Secondary clarifiers provide two key functions in the BNR process: (1) capture biomass and return biomass to the bioreactor to sustain the BNR process and (2) provide quiescent conditions that allow particles to settle and produce clear effluent. A well settling biomass can allow the BNR process to operate at a higher mixed liquor concentration and improve process capacity, stability, and effluent quality.

Producing low effluent TSS from the secondary clarifier also reduces particulate nutrients in the effluent.

This requires not only good solids separation and compaction, but also the ability to capture small and light particles that will escape over the clarifier weir. The key to improving solids capture in a secondary clarifier is to (1) provide flocculation of the biomass to entrap small particles into larger flocs, (2) improve the internal flow regime within the clarifier by minimizing the adverse effects of solids and/or thermally induced density currents, and (3) manage the sludge inventory in the clarifier to avoid denitrification, which may inhibit settleability by producing N gas. Flocculation compartments are typically used at the front end of rectangular clarifiers and in the center of circular clarifiers to promote flocculation. The adverse effects of density current could be minimized by the use of baffles that direct the flow in a favorable way to provide a quiescent environment for solids to settle while avoiding sludge resuspension.

Clarifier performance is controlled by the biomass settling properties, which is dependent on the influent composition, process arrangement, operation, and many other factors. BNR processes typically produce a well settling biomass, but nuisance conditions can occur that allow filaments to grow and impair settleability. Strategies to improve settleability include process changes to select for non-filaments, chemical addition, or selective retention of well settling/granular solids.

Fact Sheet Application Checklist

R = topics that are relevant/covered in this fact sheet
PR = topics that are possibly relevant to this fact sheet

Category	R	Intensification
	R	Chemical addition
		Carbon management
		I&C strategies
		Sidestream mgmt.
	PR	Energy savings
		Chemical savings
		Operational savings
		Other means of NutRem
Nutrient		Ammonia
		NOx
	PR	TN
		Ortho-P
	R	TP
Scale (design flow)	PR	Small (<1 mgd)
	R	Medium (1–10 mgd)
	R	Large (>10 mgd)

Goal	R	Improve reliability
	R	Reduce nutrient
		Reduce O&M cost
Group	PR	Optimize existing CNR
	PR	Optimize existing TNR
	PR	NutRem in secondary plant
Process		Small
		Pond
	R	Fixed film (secondary)
	R	Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
	R	Tertiary NutRem (TNR)
		Other

CAS = conventional activated sludge (BOD only)
NAS = nitrifying activated sludge (without denitrification)
CNR = conventional nutrient removal no chemical/no filter, etc.
TNR = tertiary nutrient removal with chemical, filter, etc.

Technology Summary Evaluation

Footprint	3	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	5	Technology ranking based (LIFT) see below*
Energy use	3	Scale 1–5: 1 = use much less; 3 = use similar to conventional; 5 = use much more
O&M cost	3	Scale 1–5: 1 = cost much less; 3 = cost similar to conventional; 5 = cost much more
Material/consumables	1	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1	Scale 1–3: minimal/none = 1; some = 2; significant = 3 (e.g., chemical process)

* Technology ranking based on Leaders Innovation Forum for Technology (LIFT) Water Research Foundation (WRF) Technology Development Level (TDL) definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
5 = conventional

Descriptions/Evaluation

Strategy	Optimization of primary sedimentation basins and secondary clarifiers
Description	Primary sedimentation basins and secondary clarifiers are used to removal suspended solids (SS). Primary sedimentation basins remove TSS and BOD from influent wastewater and reduce the organic load to the biological secondary, conventional nutrient removal (CNR), and tertiary nutrient removal (TNR) process. Secondary clarification is used to (1) capture and then return biomass to the activated sludge process and (2) produce an effluent very low in TSS. A clear effluent from the secondary clarifier is a key to meeting effluent nutrient requirements because TSS contains particulate N and phosphorus (P).
Application	Primary sedimentation basins remove wastewater organic solids. This can divert organics to anaerobic digestion for energy production and reduce biomass production in secondary treatment and increase treatment capacity; however, too much organic removal could negatively impact nutrient removal. Secondary clarifiers must retain biomass for the BNR process and also produce low TSS in the effluent to reduce nutrients associated with the solids. Producing high-quality effluent (low TSS) is critical for nutrient removal.
Constituents removed	Clarifiers remove particulates and particle-associated nutrients. This includes TSS, BOD, total phosphorus (TP), and total nitrogen (TN).
Development status*	LIFT TDL 5: Primary sedimentation and secondary clarification are all widely practiced at WRRFs. Optimization strategies such as the use of baffle to improve the internal flow regime and chemical addition to primary sedimentation basins or secondary clarifiers for enhanced particle capture are also common.
O&M considerations	Clarifiers require little maintenance. Maintaining good settleability of the biomass can be challenging. BNR plants are known to produce good settling sludge; however, nuisance organisms (mostly excessive filaments) interfere with settling and compaction of solids. Chemical handling and storage would be required for CEPT.
Benefits	Increased biogas production from anaerobic digestion with improved primary sedimentation basins organic removal. Carbon diversion from BNR will reduce biomass growth and increase capacity to raise SRT or capacity of BNR. Improved secondary clarifier performance allows the BNR process to operate at a higher mixed liquor concentration and reduce particulate nutrients in effluent.
Limitations	Poor hydraulics in a clarifier is the main hindrance to superior performance. Improving the internal flow regime in the clarifier will improve performance.
Design considerations	Clarifier performance is typically related to the surface overflow rate (SOR) and hydraulic retention time (HRT) in the clarifier. Solids loading rate typically limits the capacity of a secondary clarifier. Consider the process performance impacts of reduced BOD load to the BNR process from improved primary sedimentation basin performance.
Potential fatal flaws	Lower BOD load to the BNR process from improved primary clarification may limit denitrification and/or EBPR.
Footprint requirements	Optimizations including baffle additions and flocculation zones require no additional footprint. Chemical addition for CEPT requires chemical storage facilities.
Residuals	No change in residuals except when chemicals are added.
Cost considerations	Operating costs are associated with pumping and chemical addition. Clarifier mechanisms require minimal energy.

Past experience	Primary sedimentation basin optimization with baffle installation improves TSS removal from 50% to above 70% with baffle installed, Central San, Martinez, California. A series of baffles placed in a rectangular sedimentation basin improved TSS removal from 38% (at overflow rate of 2,000 gallons per day [gpd] per square foot [ft^2]) to 60% (at overflow rate of 4,000 gpd/ft^2). At an overflow rate of 7,000 gpd/ft^2, the removal was 49%. Dublin San Ramon Services District, Dublin, California. The baffle-equipped primary sedimentation basins achieved a TSS removal efficiency of approximately 60% at average flow rate and 45% at overflow rates of 4,500 gpd/ft^2. Cities of Lacey, Olympia, and Tumwater and Thurston County (LOTT) Clean Water Alliance, Olympia, Washington.
Publications	Borkman, C., K. Lew, and H. Gerges. 2004. “Optimizing Clarifier Inlet and Outlet Arrangement Leads to Improved Performance and Big Savings.” Proceedings of the Water Environment Federation Annual Conference, New Orleans, Louisiana, October. Chu, I., A. Griborio, P. Pitt, M. Ahmad, G. Chiu, J. Desai, J. Wang, and D. Freitas. 2015. “Optimization of Clarifier Performance to Enhance Biological Nutrient Removal.” Nutrient Symposium. San Jose, California: WEF 2015. Gerges, H. 2008. ”Thirty Years of Sedimentation Tank Modeling – Learning from Experience,” Proceedings of WEFTEC 2008, Chicago, Illinois. Gerges, H.Z. and J.A. McCorquodale. 1998. “Winter Temperature Gradients in Circular Clarifiers,” Water Environment Research. Gerges, H.Z. and K.M. Ho. 2018. “Smarter and Greener Design and Operation of Primary Sedimentation Tanks Without Surplus Activated Sludge Co-Settling Using Three-Dimensional Computational Fluid Dynamic Modelling.” Proceedings of WEFTEC 2018, New Orleans, Louisiana. Gerges, H.Z. and M. Bodeaux. 2006. “Mathematical Modeling Enables a California Facility to Optimize the Performance of its Secondary Clarifiers Cost-Effectively,” WT&E, Vol. 18, No. 4, April. Gerges, H.Z., H.H. Benjes, H.L. Cronister, J.B. Neethling, D. Wilson, and N. Cable. 2001. “Unlock Your Plant’s Hidden Potential,” Water Environment and Technology/Operations Forum, September. Griborio, A., P. Pitt, R. Latimer, J.A. McCorquodale. 2009. “Optimization of Secondary Clarifiers in BNR/ENR Applications: Four Case Studies Comparing Different Clarifier Geometries.” WEF’s 82nd Annual Technical Exhibition and Conference. Orlando, Florida: WEFTEC 2009. Roe, P., H. Gerges, and E. Hielema. 2015. “Designing primary sedimentation to minimize footprint and to balance energy efficiency and biological nutrient removal objectives.” WEF’s 88th Annual Technical Exhibition and Conference. Chicago, Illinois: WEFTEC 2015 4673–4696. Shima, C. 2019. “Making Primary Sedimentation Basin more efficient using innovative baffle system.” WEF’s 92nd Annual Technical Exhibition and Conference. Chicago, Illinois: WEFTEC.
Related fact sheets	1110: Increase Biomass 1150: Use of Chemicals to Improve Nutrient Removal
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Note

* Technology ranking based on LIFT WRF TDL definitions:
1 = bench research and development
2 = small-scale pilot
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5 = conventional (https://www.waterrf.org/sites/default/files/file/2019-07/LIFT%20Scan%20Application-LIFT%20Link%2BHub_0.pdf : accessed September 2020)

Additional Information

Both primary sedimentation basins and secondary clarifiers are candidates for optimization at many water resource recovery facilities (WRRFs). Optimization reflected in higher solids capture or clarification capacity can happen in different ways:

- Enhancing flocculation of the influent solids with or without chemical addition
- Promoting better internal flow regime using baffles and optimal effluent arrangements
- Managing the sludge inventory in the clarifier
- Improving solids settleability (in case of secondary clarifiers) for biological mixed liquor (improve sludge volume index [SVI])
- Improve solids settleability for biological mixed liquor (improve SVI)
- Improve flow distribution between clarifiers

Enhancing Flocculation of Influent Solids with or without Chemical Addition

Flocculation of primary sedimentation basins without chemical addition can improve solids capture. CEPT is also commonly used to further improve solids capture. TSS removal can be improved from a typical 50%–55% removal to 80% under some instances. Chemical addition reduces the level of non-settleable solids and increases the settling velocities of the settling solids.

The high removal will increase the ability to raise the SRT in the biological process to free up some capacity in the basin for nitrification, denitrification, and EBPR. Because the reduction in BOD could negatively impact denitrification and EBPR this strategy should be evaluated by a subject matter expert to determine the optimal performance. Using sludge or other fermenters could be considered to supplement carbon to anoxic or anaerobic zones.

The use of flocculation baffles in primary sedimentation basins has been proved to be very effective in reducing the level of non-settleable solids. When flocculation baffles are combined with mid-tank and sludge protecting baffles, primary sedimentation basins can achieve removal efficiencies as high as 75% to 80% at average flow conditions. There are a few advantages of using baffles over chemicals in optimizing primary sedimentation basins:

1. Baffles are more cost-effective than chemicals. Chemicals are expensive to supply and require storage tankage and management systems and must adhere to strict safety guidelines.
2. Baffles can be customized to target a desired removal efficiency at a specific flow rate. For example, the baffle system could be designed to improve performance during only storm events while maintaining “normal” performance under average flow conditions to allow carbon to pass through to the downstream biological system. Adding chemicals year round could lead to unnecessary high BOD removal at average and low flow conditions.
3. Baffle systems are static and do not require additional maintenance. They also do not require operator attention or adjustments for different flow conditions.

For secondary clarifiers, flocculating compartments in front of rectangular clarifiers or in centerwells of circular clarifiers can improve solids capture. These compartments do not require mechanical mixing but rely on carefully designed baffles to flocculate mixed liquor and reduce effluent TSS. Computational Fluid Dynamics (CFD) modeling is a useful tool to determine the flocculating centerwell size and depth.

Reference

Gerges, H.Z., and K.M. Ho. 2018. "Smarter and Greener Design and Operation of Primary Sedimentation Tanks Without Surplus Activated Sludge Co-Settling Using Three-Dimensional Computational Fluid Dynamic Modelling." Proceedings of the WEFTEC 2018, New Orleans, Louisiana.

Promoting Better Internal Flow Regime by Using Baffles

Improving the internal hydraulics of primary sedimentation basins could be achieved through strategically placed internal baffles and optimal effluent arrangements. The use of internal baffles has been proved in the last decade with many successful applications. The baffle systems usually consist of flocculation baffles, a series of mid-tank baffles (in case of rectangular sedimentation basins), and sludge protector baffles. The optimal effluent arrangements are a series of transversal launders in rectangular tanks and inset launders in circular tanks.

The improved performance of the sedimentation basins equipped with internal baffles has been demonstrated by conducting a parallel comparison between basins with and without the baffles. Also, historical data comparing the performance of the basins before and after modifications proved that modified clarifiers outperformed unmodified ones significantly.

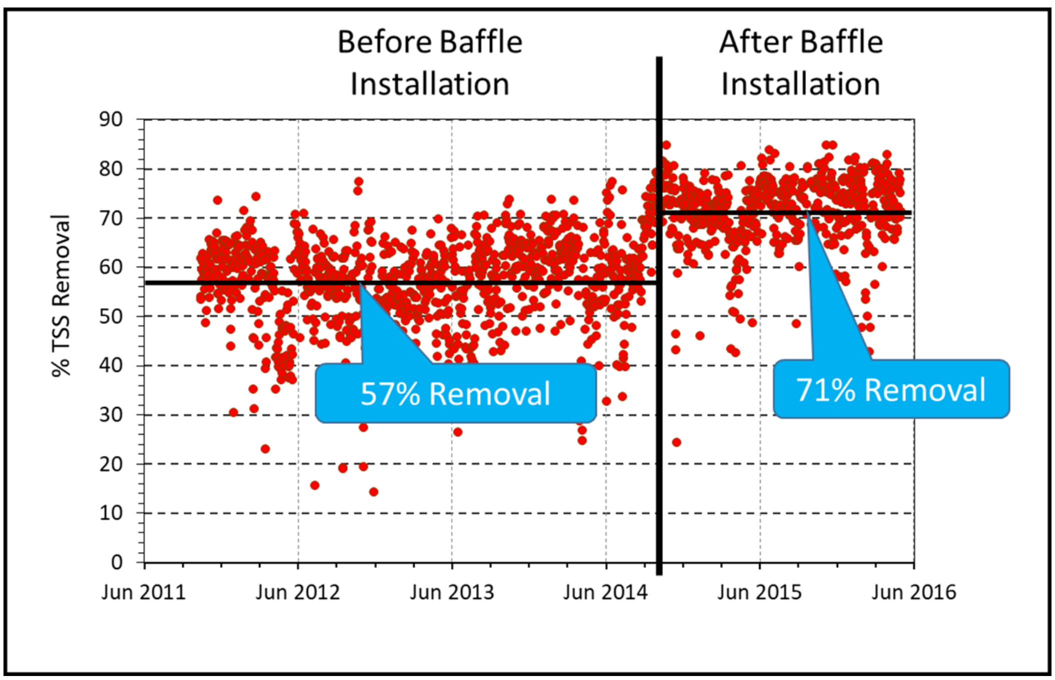

Figure 1. Increase in TSS Removal through Strategic Placement of Baffles in a Primary Sedimentation Basin.
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Managing the Sludge Inventory in the Clarifier

Managing the sludge inventory in primary sedimentation basins and secondary clarifiers is key to optimal performance. In primary sedimentation basins, it is crucial to ensure that influent does not interfere with the settled sludge to avoid resuspending the solids. The sludge concentration in primary sedimentation basins ranges from as low as 0.5% to as high as 6.0%. Typically, the sludge blanket could be protected from the incoming flows by placing a sludge canopy (also known as a sludge protector system) on top of the sludge hopper.

In secondary clarifiers, protecting sludge blankets is equally critical for the overall performance of the clarifiers. Resuspension of the blanket leads to high effluent TSS, BOD, and particulate nutrients, and could cause solids washout and have a severe adverse effect on the biological treatment systems because of excessive loss of biomass. In BNR plants, maintaining a sludge blanket less than 1 foot would be recommended to avoid sludge resuspension under high flows or blanket denitrification, especially if the clarifier influent nitrate level is greater than 10 milligrams per liter (mg/L).

Improve Solids Settleability for Biological Mixed Liquor (Improve SVI)

Good settleability of mixed liquor is critical to solid removal and thickening in secondary clarifiers. The settleability is measured as the SVI. Excessive filamentous organism growth results in a high-SVI sludge that settles slowly and compacts poorly. A skilled process analyst/microbiologist can provide an assessment of the causes and controls that can be used to improve settleability.

Some of the commonly used strategies to improve SVI and sludge settleability are as follows:

- Find the root cause for excessive filament growth and take corrective action. Some of the common causes are:
  - High food-to-microorganism (F/M) ratio associated with low dissolved oxygen (DO) in activated sludge
  - Presence of readily degradable organics such as volatile fatty acids (VFAs) in a mixed aerobic zone
  - Septic wastewater that contains sulfides and VFAs
  - High fats, oils, and greases
- Create an anaerobic selector (similar to the anaerobic zone in a BNR process), which will allow floc-forming organisms to remove the readily degradable substrate and restrain the filament growth.
- Create an anoxic selector (similar to the denitrification zone in a BNR process), which will allow denitrifying organisms to remove the readily degradable substrate and restrain the filament growth.
- Adding chlorine to return activated sludge (RAS) (or other location) to kill and retard filament growth is a universal strategy that can easily be implemented in an existing WRRF. A metabolic selection is a more elegant approach.

Improve Flow Distribution between Clarifiers

Uneven flow split between clarifiers represents a major problem at many treatment plants. This is especially important for BNR WRRFs because the better performance of the underloaded clarifiers does not compensate for the poorer performance of the overloaded clarifiers, leading to suboptimal performance of the whole clarification process.

In case of rectangular primary sedimentation basins and secondary clarifiers, open channels are frequently used to convey flow to and split flows between the clarifiers. The flow split between the clarifiers depends mainly on the balance between the flow momentum and the friction losses in the channel. One way to balance the effect of momentum and friction is to increase the head loss through the clarifier inlet ports or gates compared to the head loss in the channel. However, the higher head loss could lead to hydraulic bottlenecks upstream. CFD modeling has been proved to assist design of flow-balancing vanes. The main purpose of the vanes is to guide the flow without creating excessive head loss.

In case of circular primary and secondary clarifiers, the use of splitter boxes and weirs is always recommended to ensure proper flow split between clarifiers.

Abbreviations

BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CEPT	Chemically enhanced primary treatment
CFD	Computational Fluid Dynamics
CNR	Conventional nutrient removal
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
F/M	Food to microorganism (ratio)
ft^2	Square foot/feet
gpd	Gallon(s) per day
HRT	Hydraulic retention time
I&C	Instrumentation and controls
L	Liter(s)
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
LOTT	Cities of Lacey, Olympia, and Tumwater and Thurston County (Clean Water Alliance)
mg	Milligram(s)
mgd	Million gallons per day
N	Nitrogen
NAS	Nitrifying activated sludge
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
RAS	Return activated sludge
SOR	Surface overflow rate
SRT	Solids retention time
SS	Suspended solids
SVI	Sludge volume index
TDL	Technology Development Level
TN	Total nitrogen

TNR	Tertiary nutrient removal
TP	Total phosphorus
TSS	Total suspended solids
UV	Ultraviolet
VFA	Volatile fatty acid
WRF	The Water Research Foundation
WRRF	Water resource recovery facility