WRF 4973 Fact Sheet: ID 1140

Strategy: Process Intensification

Optimize BNR Effectiveness

Dissolved Oxygen Carryover from Aerated to Unaerated Zone.
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Vortex Free Mixing.
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This fact sheet contains some strategies to improve the performance of an existing activated sludge biological nutrient removal (BNR) process. The typical BNR basin has multiple zones (also called basins, reactors, etc.) that each have a different function, internal recycle streams that distribute liquid to other zones, and influent and return activated sludge (RAS) flows. The operational strategy, layout, and arrangement of these different zones can impact the downstream or upstream zone. Within a zone, short circuiting can reduce the process efficiency.

The factors that impact zone efficiency fall into three categories: short circuiting, dissolved oxygen (DO) or NO_x (oxidized nitrogen species, which include nitrate plus nitrite) interference, and equipment limitations. Multiple basins are frequently used to create a plug flow process. However, short circuiting can occur within each basin from the location and directional flow infeed point, the rotation of mixers, or density differences. Oxidized nitrogen (NO_x) from influent, aerated zones, or RAS will impact performance of anaerobic/fermentation zones. Similarly, DO in internal recycle flows from an aerobic zone or DO in the influent could impact performance if these streams are sent to anaerobic and anoxic zones. Water flowing over baffles/weirs will entrain DO that will impact downstream unaerated zones. High-intensity mixing creates small vortices on the water surface that entrain oxygen. Equipment limitations can restrict turndown capability.

All these factors can be mitigated. See the Additional Information section below for more information.

Fact Sheet Application Checklist

R = fact sheet relevant to item
PR = fact sheet is potentially relevant to item depending on application, existing conditions, etc.

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

Goal		Improve reliability
	R	Reduce nutrient
	R	Reduce O&M cost
Group	R	Optimize existing CNR
	R	Optimize existing TNR
	R	NutRem in secondary plant
Process	R	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*	1–5	Technology ranking based (LIFT) see below*
Energy use	3–5	Scale 1–5: 1 = use much less; 3 = use similar to conventional; 5 = use much more
O&M cost	1–5	Scale 1–5: 1 = cost much less; 3 = cost similar to conventional; 5 = cost much more
Material/consumables	1–2	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	1–2	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	Optimize BNR performance through changes in operation strategy, process control, and minor modifications
Description	Optimization of BNR system can include a wide array of changes or modification to operation strategy, control logic, set points, recycle rates, mixing energy, etc. Specific examples include: • Slowing mixer speed to eliminate vortex DO entrainment • Use swing zones to optimize anaerobic zone (ANR), anoxic zone (ANX) hydraulic retention time (HRT) • Modify primary sludge thickening to increase volatile fatty acids (VFAs) in BNR influent • Lower DO set point mixed liquor recycle (MLR) recycle zone • Modify aeration control to maximize simultaneous nitrification and denitrification (SND) • Implement online analyzer based chemical feed control
Application	Any BNR plant that requires some additional capacity (<20%), reduce effluent phosphorus (P) or nitrogen (N), and/or reduce operation cost
Constituents removed	N and/or P
Development status*	The development status is moot for optimization as there is no risk of stranded assets. Utilities are encouraged to optimize systems through small incremental changes that carry little risk.
O&M considerations	Optimization can be with respect to operations and maintenance (O&M) but in most cases optimization does tighten down operation such that greater operator attention and more real-time monitoring is required.
Benefits	Operation cost reduction and/or improved treatment performance at minimal capital cost.
Limitations	The main limitation is the existing infrastructure, especially power and instrumentation and controls (I&C) connectivity. Adding a mixer is simple when spare conduits for power and controls are available. The same is true for online analyzers and probes. In practice, electrical and I&C cost will be the determining factor in whether something requires a capital project.
Design considerations	Optimization itself should include only minor design items such as adding mixers, making changes to the control logic, or adding instrumentation.
Potential fatal flaws	Fatal flaws are unlikely but it is very site- and case-specific.
Footprint requirements	None
Residuals	Some reduction in effluent nutrients but otherwise no changes.
Cost considerations	Varies depending on the existing facility but should be marginal (<5% of annual operation budget).
Past experience	Webinar 8: Optimization of Nutrient Removal WRRFs

Publications	Brischke, K., W. Anderson, G. Budzynski, M. Alvis, I. Myers, and L. Rieger. 2018. “Taking Ammonia Based Aeration Control to the Next Level: Real World Experience and Lessons Learned.” WEF’s 91st Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC. Klaus, S., M. Kinyua, K. Chandran, B. Wett, S. Murthy, and C. Bott. 2016. “Comparison of ABAC and AVN aeration control strategies for efficient nitrogen removal.” WEF’s 89th Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC. Menniti, A. and K. Eberhardt. 2017. “Optimizing aeration system performance and efficiency at the Durham Advanced Wastewater Treatment Facility.” Annual Conference: PNCWA. Miller, M., P. Regmi, and J. Jimenez. 2019. “Sensors Versus Analyzers: The Case for Ammonia-based Aeration Control.” Proceedings of the 92nd Water Environment Federation’s Technical Exhibition Conference (WEFTEC), Chicago, Illinois. Reardon, D. 1998. “Energy Usage Wastewater treatment plants.” Waterworld, August 31. Regmi, P., K. Chandran, and J. Jimenez. 2017. “Full-scale evaluation of carbon and energy efficient combined nitrogen and phosphorus removal with advanced aeration and settleability control.” Nutrient Symposium. Fort Lauderdale, Florida: WEF. Rieger, L., R.M. Jones, P.L. Dold, and C.B. Bott. 2014. “Ammonia-Based Feedforward and Feedback Aeration Control in Activated Sludge Processes.” Water Environment Research. 86(1), 63–73. Schraa, O., L. Rieger, J. Alex, and I. Miletic. 2019. “Ammonia-based aeration control with optimal SRT control: improved performance and lower energy consumption.” Wat. Sci. Tech. 79(1), 63–72. Smith, R., J. VanDommelen, and J. Holton. 2018. “Optimization of Aeration Control for Nitrogen Removal in an Oxidation Ditch Using Online Ammonium and Nitrate Sensors.” WEF’s 91st Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC. U.S. DOE. 2019. “Energy Data Management Manual Wastewater Treatment.” DOE/EE-1700 Better Buildings, U.S. Department of Energy, December 2017.
Related fact sheets	1450: DO Control to Increase Denitrification 1510: Improve Control, Stability, and Efficiency 1710: Optimize Available Equipment
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Note

* Technology ranking based on LIFT WRF TDL definitions:
1 = bench research and development
2 = small-scale pilot
3 = full-scale pilot (demonstration)
4 = pioneer stage (production and implementation)
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

The factors that impact the zone efficiency fall into one of three categories:

- **Short circuiting:** Short circuiting is when flow takes an unintended, shorter path. This effectively reduces the retention time of the flow that short circuits, which can significantly impact the ability for the process to treat the flow. Short circuiting can occur for multiple reasons, such as mixing, which induces certain flow patterns and density differences between influent streams.
- **DO or NO_x (oxidized nitrogen, nitrate plus nitrite) interference:** Oxidized nitrogen (NO_x) from nitrifying aerated zones or RAS will impact the performance of anaerobic/fermentation zones. Similarly, DO from aerobic zones and the process influent will impact the performance of both anaerobic and anoxic zones. Water flowing over baffles/weirs will entrain DO that will impact downstream unaerated zones. High-intensity mixing in unaerated zones may also entrain DO in these basins.
- **Equipment limitations:** High-intensity mixing creates small vortices on the water surface that entrain oxygen. Turning down equipment may be desirable during off-peak hours of operation or low loading conditions to save; however, equipment may be limited in its capability to turn down.

See Table 1 for some of the issues/problems and potential resolutions for consideration.

Table 1. Zone Problems/Inefficiencies and Potential Solutions.

Category	Problem/Inefficiency	Potential Solutions
DO interference	MLR to ANX returns DO from aerobic zone	Reduce DO in aeration basin at MLR intake; add deoxygenation zone at MLR intake
DO interference	Water dropping over primary clarifier weir entrains DO	Reduce the weir drop by raising downstream liquid level
DO interference	Entrained DO in weir flow split	Raise water level downstream. Switch to control valve/meter flow split.
DO interference	Minimize mixing in ANR zone	Create deep anaerobic conditions by turning mixers off most of the time
Short circuiting	Single large aerobic zone creates random flow pattern resulting in poor DO control and “dead zones” in corners	Add baffles to create a plug flow through the basin. Flow pattern can be serpentine or in circular pattern (oxidation ditch style).
Short circuiting	Influent with different density from mixed liquor travels quickly through basin	Add deflection baffles, direct flow to floor, distribute influent over broad distance
Short circuiting	MLR pump creates circular flow in unaerated zone basin	Add deflection baffles, direct flow to floor
Short circuiting	Mixer rotations cause circular flow pattern in unaerated zone	Add baffles, use counter-circular mixer (reverse rotation of one or more)
Short circuiting	Mechanical surface aerators create anoxic conditions because of internal liquid circulation (a “donut” anoxic ring)	Take advantage of ANX to denitrify if possible
Equipment	Screw pumps feeding unaerated zone (example RAS pumps)	Minimize oxygen supply to ANR and ANX

Category	Problem/Inefficiency	Potential Solutions
Equipment	Mixing equipment creates vortices in unaerated zone that entrains DO	Reduce mixing intensity
Equipment	Blowers cannot be turned down to reduce aeration during low loading conditions (overnight, initial startup when flow is low).	Add “jockey” blower to operate during low load periods. Blow off air into empty basin or into atmosphere (not energy efficient). Balance energy and process objectives.

Abbreviations

ANR	Anaerobic zone
ANX	Anoxic zone
BNR	Biological nutrient removal
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
DO	Dissolved oxygen
HRT	Hydraulic retention time
I&C	Instrumentation and controls
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
MLR	Mixed liquor recycle
N	Nitrogen
NAS	Nitrifying activated sludge
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
RAS	Return activated sludge
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
SND	Simultaneous nitrification and denitrification
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
UV	Ultraviolet
VFA	Volatile fatty acid
WRF	The Water Research Foundation
WRRF	Water resource recovery facility