WRF 4973 Fact Sheet: ID 1401

Strategy: Carbon Management

Optimize Carbon Use for Nutrient Removal

Primary Sludge Fermenter.
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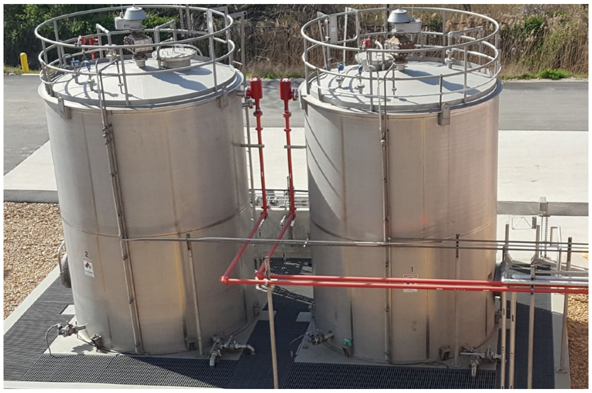

External Carbon.
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Both nitrogen (N) and biological phosphorus (P) removal processes require a readily biodegradable carbon source. Some process approaches can also take advantage of slowly degradable particulate organics that are fermented/hydrolyzed into readily biodegradable organics and used by denitrifying organisms and polyphosphate-accumulating organisms (PAOs) for enhanced biological phosphorus removal (EBPR). Many wastewaters are short on available carbon to achieve low effluent nitrogen, low effluent phosphorus, and to maintain reliable performance. The nutrient:carbon ratio (biochemical oxygen demand [BOD]:N or chemical oxygen demand [COD]:N and BOD:P or COD:P) is used as an indicator of achieving reliable denitrification and/or EPBR.

Supplemental carbon can be added to or generated in the process to improve the biological nutrient removal (BNR) influent COD:nutrient ratio. External carbon sources include not only chemicals (such as acetate) but can also be from industrial sources such as brewery waste (see related fact sheets below). Water resource recovery facility (WRRF)-generated carbon typically comes from a fermentation process (primary sludge fermentation or mixed liquor fermentation). Note that using WRRF-generated carbon lowers the digester gas yield (5%–20%).

The BNR process configuration and process design can be optimized to maximize the use of available carbon for denitrification and EBPR by limiting the direct oxidation of COD with dissolved oxygen (DO). The efficiency of the anoxic zone (for denitrification) and anaerobic zone (for EBPR) is reduced when DO in the feed streams is high.

WRRFs that produce green energy from anaerobic digester gas face a second balance: directing influent carbon to the BNR reduces the carbon feed to the anaerobic digesters and reduces gas production. In this case the operator/designer may need to establish the optimal balance for beneficial use of the available carbon at the WRRF.

This fact sheet provides an overview of carbon management strategies to maximize nutrient removal in the BNR process. Two related fact sheets address fermentation (Fact Sheet 1410) and DO control to reduce carbon use (Fact Sheet 1450).

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
		Chemical addition
	R	Carbon management
	R	I&C strategies
		Sidestream mgmt.
		Energy savings
	R	Chemical savings
	R	Operational savings
		Other means of NutRem
Nutrient		Ammonia
	R	NOx
	R	TN
	R	Ortho-P
	R	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
		NutRem in secondary plant
Process		Small
		Pond
		Fixed film (secondary)
		Conventional act. sludge (CAS)
		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	N/A	Compared to conventional (1 = much smaller; 3 = conventional; 5 = much larger)
Development status*	5	Technology ranking based (LIFT) see below*
Energy efficiency	3	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M impact	3	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
Material/consumables	2	Scale 1–3: minimal = 1; some = 2; significant = 3 (e.g., UV lamps/membranes)
Chemical use	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	Carbon management of influent wastewater to balance demand between phosphorus and nitrogen removal as well as carbon diversion for gas generation
Description	Carbon management considers the best use of available organics (BOD) to meet the needs for biological P and N removal. Diverting carbon from influent to anaerobic digestion to increase gas generation will decrease available carbon for nutrient removal and reduce biological biomass production and potentially increase BNR capacity. This fact sheet addresses strategies for carbon management to optimize nutrient removal. There are essentially three general categories: • Fermentation processes to generate readily biodegradable organics such as volatile fatty acids (VFAs) to enhance biological N and/or P removal. • Changing process operation to use available carbon more efficiently such as operating at lower DO, avoiding DO recycled to unaerated zones, and minimizing oxidized nitrogen in return sludge flow to anaerobic zones. • Reducing carbon demand through process changes to shortcut N removal, deammonification, P recovery, or sidestream P sequestration.
Application	Carbon management is a balance to achieve different objectives: • Improve denitrification for N removal • Improve biological P removal • Reduce biomass growth and aeration energy • Increase energy generation from anaerobic digester gas
Constituents removed	Carbon management can help improve N and P removal.
Development status*	Mostly established (LIFT TDL 5). New processes and strategies are continuously evolving such as RAS fermentation or mainstream anammox.
O&M considerations	Depends on selected carbon management strategy. Carbon management is dynamic and requires periodic adjustments to account for seasonal changes in influent characteristics.
Benefits	Reduced operation cost and improved nutrient removal performance and/or resource recovery. Avoids or reduces the need to add external carbon.
Limitations	Carbon management is limited by the available carbon in the influent and influent organic fractions. Slowly biodegradable carbon can be fermented to readily biodegradable carbon to enhance denitrification and biological P removal.
Design considerations	Use of fermenters such as primary sludge fermenters for producing readily degradable carbon will reduce gas production in anaerobic digestion. Use of fermenters such as primary sludge fermenters can be a source of odor.
Potential fatal flaws	None
Footprint requirements	Depends on selected carbon management strategy
Residuals	Similar to conventional nutrient removal
Cost considerations	Depends on selected carbon management strategy; there are potential savings on external carbon cost if on-site fermentation is implemented, for example; however, capital costs and return on investment periods should be considered.
Past experience	Depends on selected carbon management strategy
Publications	Benisch, M., J.B. Neethling, R. Bhattarei, and R. Baur. 2002. "Primary Sludge Fermentation—Results from two full-scale pilots at South Austin Regional (TX, USA) and Durham WWTP (OR, USA)." WEFTEC.

	Benisch, M., R. Baur, JB Neethling, and A. Zaklikowski. 2009. "Results from a Full Scale UFAT VFA Generation Capacity Study." Proceedings of the Water Environment Federation 2009(12):4330–4341. Rabinowitz, B. and M.K Fried. 2010. "Primary Sludge Fermenters in BNR Plants: Are They Cost-Effective for Meeting Effluent Phosphorus Limits?" WEF's 83rd Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC. Regmi, P. and J. Jimenez. 2016. "Process intensification of a long SRT BNR plant via carbon redirection and carbon efficient nitrogen removal." WEF's 89th Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC 2016 4374–4379. WRF (The Water Research Foundation). 2019. "Fermenters for Biological Phosphorus Removal Carbon Augmentation" from the Nutrient Removal Challenge. https://www.waterrf.org/sites/default/files/file/2021-07/Fermenters-for-BPR.pdf.
Related fact sheets	1310: External Carbon Sources 1410: Fermentation 1450: DO Control to Increase Denitrification
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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 objective of carbon management is to balance or optimize the use of the influent carbon between P and N removal as well as energy generation and resource recovery.

Table 1 includes a list of processes, carbon use, and the corresponding use of carbon in the process.

Table 1. Carbon Use and Carbon Generating Processes.

Process	Carbon Use/Generation/Impact	Comments
Phosphorus removal	VFAs, mainly acetic and propionic acid, is needed for EBPR. Influent ratio for stable EBPR is 30 milligrams (mg) BOD/mg P. Influent VFA is typically insufficient during winter and wet weather seasons.	Available VFA in wastewater influent varies widely depending on local climate, size of service area, collection system hydraulic retention time (HRT), inflow and infiltration, and use of collection system odor control chemicals. Typical concentration is in the 20–40 mg/L range for summer conditions and in the 0–5 mg/L range during winter or wet weather conditions.

Process	Carbon Use/Generation/Impact	Comments
Nitrogen removal	Denitrification requires a carbon source as an electron donor. Any readily biodegradable carbon can be used. 4–6 mg/L of readily biodegradable chemical oxygen demand (rbCOD) is required to denitrify 1 mg of nitrate-N.	A fraction of the required rbCOD may be generated in a return activated sludge (RAS) or mixed liquor suspended solids (MLSS) anaerobic/fermentation zone.
Primary sludge fermentation	Generate VFA from an influent carbon source by fermenting primary sludge.	Fermentation of primary sludge reduces digester gas yield ±10% by redirecting carbon back to the BNR process vs. the digester. Primary sludge fermentation may be a source of odor.
RAS and MLSS fermentation	Generate VFAs by fermenting a portion of RAS or MLSS. Requires less or no carbon from influent, which allows for influent carbon to be directed to N and P removal.	RAS and mixed liquor fermentation are still an emerging process with ongoing WRF research. Several full-scale WRRFs have demonstrated success.
SNDN	In low-rate systems or when excess capacity is available, simultaneous nitrification and denitrification (SND) may improve carbon management by denitrifying at low DO. A portion of SND may be removed through shortcut N removal.	Can be achieved while maintaining a lower DO or through cyclical aeration. WRRFs with very low effluent ammonia limits may require additional aeration zone following SND.
CEPT	Option to increase primary carbon removal to direct more carbon toward anaerobic digestion and increase gas/energy generation.	Does not enhance biological N or P removal. CEPT will chemically remove P and also reduce solids and BOD load to biological process, thus reducing the biomass production and increasing the capacity of the aeration basin.
Primary filtration	Option to increase primary carbon removal to direct more carbon toward anaerobic digestion and increase gas/energy generation.	Does not enhance biological N or P removal. Primary filtration will divert solids and BOD load to anaerobic digestion for gas production. This reduces the organic load to the biological process, thus reducing the biomass production and freeing up capacity of the aeration basin to implement nutrient reduction in the basin. Process at LIFT TDLs 3–4.
External carbon (organic waste product)	Industrial waste carbon (glycerol, sugar water, brewery waste, etc.) can be used as a carbon source for nitrogen removal. For EBPR, conversion to organic acids is required in the EBPR process or in an external fermenter.	Waste carbon varies in composition and strength; each batch must be analyzed to adjust during operation. Waste is preferably brought into the WRRF as a separate stream and its use managed within the WRRF.
External carbon (stock chemical)	Chemicals (methanol, ethanol, glycerol, etc.) can be used as a carbon source.	Pure chemical with consistent concentration. Methanol use for denitrification requires acclimation to grow methylotrophic organisms. Most other chemicals are used by ordinary heterotrophic organisms in the activated sludge and can be fed on demand.

Process	Carbon Use/Generation/Impact	Comments
Direct dewatering of EBPR waste activated sludge (WAS)	Excluding EBPR WAS from anaerobic digester lowers the ammonia and P recycle and eliminates nuisance related to struvite formation in the digesters.	Gas yield from WAS is low and WAS can be diverted to compositing, direct drying after dewatering, or landfilled. For smaller facilities direct dewatering of WAS is a good alternative to improve nutrient removal by minimizing recycle loads.
A-stage high rate activated sludge	A high-rate aerobic process that captures a higher fraction of influent carbon as sludge than typical primary clarification. This is done by minimizing the amount of influent carbon oxidized and maximizing the amount of carbon captured through biophysical mechanisms such as carbon adsorption by ordinary heterotrophic organisms.	A-stage high rate activated sludge process typically oxidizes all influent VFA, making downstream biological P removal challenging.

Abbreviations

BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
COD	Chemical oxygen demand
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
HRT	Hydraulic retention time
I&C	Instrumentation and controls
L	Liter(s)
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mg	Milligram(s)
mgd	Million gallons per day
MLSS	Mixed liquor suspended solids
N	Nitrogen
N/A	Not applicable
NAS	Nitrifying activated sludge
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
P	Phosphorus
PAO	Polyphosphate-accumulating organism
RAS	Return activated sludge

rbCOD	Readily biodegradable chemical oxygen demand
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 acids
WAS	Waste activated sludge
WRF	The Water Research Foundation
WRRF	Water resource recovery facility