WRF 4973 Fact Sheet: ID 1410

Strategy: Carbon Management

Fermentation

Primary Sludge Fermenter.
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RAS and MLSS Fermentation in a Low Mixed Anaerobic Zone.
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Hydrolyzing and fermenting complex organics is an economical way to generate readily biodegradable chemical oxygen demand (rbCOD) and volatile fatty acids (VFAs) to enhance denitrification and provide a carbon source for enhanced biological phosphorus removal (EBPR). Fermentation in sewers conveying wastewater to the water resource recovery facility (WRRF) is a main source for rbCOD; on-site fermentation of primary and/or secondary sludge can supplement rbCOD in the influent to enhance nutrient removal. This is particularly important in cold weather or when stormwater infiltrates sewers.

VFAs are generated by hydrolyzing particulate and complex soluble organics in an anaerobic environment/fermenter. Two styles of fermentation processes are used. Primary sludge fermentation can occur in sludge thickeners or designed fermenters. For optimal operation, the generated VFA should be elutriated from the sludge and sent to the biological nutrient removal (BNR) process. Fermentation of return activated sludge (RAS) or mixed liquor suspended solids (MLSS) has proved to be able to produce biodegradable carbon for EBPR in the “sidestream” EBPR process. In these sidestream anaerobic zones, biomass fermentation results in VFA production and the polyphosphate-accumulating organisms (PAOs) uptake this VFA directly in the sidestream anaerobic zone. Additional carbon sources, such as primary effluent, primary sludge, primary sludge fermentate, or high-rate A-stage sludge fermentate, can also be added to these sidestream zones.

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

Goal		
	R	Improve reliability
	R	Reduce nutrient
	R	Reduce O&M cost
Group	R	Optimize existing CNR
	PR	Optimize existing TNR
	R	NutRem in secondary plant
Process	PR	Small
		Pond
		Fixed film (secondary)
		Conventional act. sludge (CAS)
	R	Nitrifying act. sludge (NAS)
	R	Conventional NutRem (CNR)
	PR	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 efficiency	1–2	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	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	Fermentation of biodegradable particulate organics to produce readily biodegradable organics
Description	Fermentation is the conversion of complex carbon molecules or colloidal organics to short-chain fatty acids. In practice this can be achieved by holding primary solids in a dedicated tank and extracting the produced VFA. While primary sludge will produce the highest yield, any biodegradable organic substrate in the sludge can be fermented. Waste activated sludge (WAS), RAS, or other degradable organic compounds can be fermented to produce VFAs. Methanogenesis is minimized (i.e., shorter solids retention time [SRT]) to optimize fatty acids production.
Application	Primary sludge fermentation is best suited to generate VFA for EBPR but can also be used as a carbon source for nitrogen (N) removal. MLSS and RAS fermentation can be incorporated into the biological process with an internal or external anaerobic/fermentation zone. Sidestream enhanced biological phosphorus removal (S2EBPR) creates a separate RAS or MLSS fermentation zone, often aside from the mainstream flow, to generate fatty acids. Typically, a controlled amount of carbon from the fermenter, screened influent, primary effluent, primary sludge, or other in-WRRF source, or from external carbon sources, is added to the sidestream anaerobic zone to enhance fermentation and improve EBPR. Ongoing Water Research Foundation (WRF) research is defining design parameters for this process. A carbon balance approach can identify the portion of available carbon via testing the apparent fermentation rate of a biomass. This rate determines the required size of the sidestream zone and the required additional carbon from non-biomass sources. S2EBPR also allows for carbon-redirection via enriching for denitrifying polyhydroxyalkanoate (PHA)-accumulating organisms that help enhance denitrification.
Constituents removed	Soluble and colloidal chemical oxygen demand (COD) is converted to rbCOD, roughly half of which is VFA.
Development status*	LIFT TDL 5 for primary sludge fermentation LIFT TDL 4 for RAS or MLSS fermentation
O&M considerations	Operational considerations vary with different strategies. Primary sludge fermenters require operator input because of odor control, scum, grease, and floating materials. The units are typically covered, and the aggressive environment could impact online instrumentation (blanket measurement, oxidation-reduction potential [ORP], etc.) RAS and MLSS fermenters are less operator-intensive and typically require small adjustments to manage anaerobic SRT and ORP in the fermenter zones.
Benefits	Adding rbCOD generated from an internal source to improve EBPR or N removal is an inexpensive method to improve BNR performance and increase process stability.
Limitations	Primary sludge fermenter yield is closely tied to pre-fermentation (carbon hydrolysis) in the collection system and primary clarifier. VFA yield will be lowest when influent is diluted and cold; these conditions determine the critical design period for the fermenter. VFA composition of the fermentate may be variable and unpredictable, unlike commercially purchased carbon products Addition of oxidative odor control chemicals such as nitrate to the collection system will inhibit VFA formation in the pipes and reduce the influent VFA. Biomass fermentation rate can vary across facilities. One major consideration is the SRT of the activated sludge process. The longer the SRT, the lower the rate of biomass fermentation.
Design considerations	Consider seasonality (temperature, dilution, etc.) for the critical design periods Modifying operation of existing primary clarifiers or gravity primary sludge thickeners to encourage fermentation and provide some elutriation of VFA could provide a boost to

	overcome a carbon limitation. Too long SRT and significant methanogenesis should be avoided. Primary sludge fermentation is a source for odors and should be addressed during design. Nuisance precipitants such as grease can clog pipes and scum control is needed. Rags and fibrous materials passing through headworks screening can become problematic. A RAS and MLSS fermenter is less odorous and does not suffer ragging and grease issues. For RAS fermentation, the concentration of RAS is a critical design parameter. The RAS pumping rate from the secondary clarifier is a critical consideration for RAS fermentation. The thicker the RAS concentration, the more effective RAS fermentation will be for a given facility.
Potential fatal flaws	Primary sludge fermentation extracts carbon from the sludge; therefore, gas production in an anaerobic digester will decrease accordingly and negatively impact any beneficial reuse of digester gas. The VFA yield is difficult to control and raises a risk of over- or under-dosing of VFA. Excessive influent grease may need to be removed to limit the impact of fermenter operation such as floating solids/scum. The low pH of fermented sludge can lead to grease buildup in sludge pipes. RAS and MLSS fermentation has fewer operational concerns. A design approach for sizing RAS and MLSS fermentation facilities has recently been published by WRF. The approach relies on an overall carbon balance for BNR design and is highly dependent on the site-specific apparent fermentation rate of biomass.
Footprint requirements	Sludge fermenter has modest footprint needs. The fermenter footprint is comparable to primary sludge thickeners. RAS and MLSS fermenters require dedicated zones in the BNR process; these typically offset the anaerobic zone needs in an EBPR process. For RAS fermenters, given that the biomass concentration is higher (i.e., 4–5 times that of MLSS in the mainstream reactor), the equivalent mainstream anaerobic zone would be larger.
Residuals	Fermented primary sludge can be directed to digesters.
Cost considerations	Construction cost comparable with similarly sized sludge thickeners. Odor control is required for sludge fermenters. RAS fermenters are similar in concrete costs, but they can be constructed independently of the hydraulic grade line given that the sidestream RAS flow is typically pumped into the RAS fermenter.
Past experience	<u>Sludge fermenters</u> • Durham Advanced Wastewater Treatment Plant (WWTP) (Oregon), Unified Fermentation and Thickening (UFAT) process (Clean Water Services) • Kalispell WWTP (Montana), static fermenter with up-flow elutriation water • Bozeman WWTP (Montana), UFAT process • West Boise WWTP (Idaho), complete mixed fermenter with thickener • Austin, Texas <u>RAS and MLSS fermenters</u> • Westbank, British Columbia • Pinery Water Plant, Colorado • Kurt R. Segler Water Reclamation Facility, Henderson, Nevada • McDowell Creek, Charlotte, North Carolina • McApline Creek, Charlotte, North Carolina • St. Cloud, Minnesota • Cedar Creek WWTP, Olathe, Kansas • Wakarusa River WWTP, Lawrence, Kansas • Medina, Ohio • Calumet Water Reclamation Plant, Metropolitan Water Reclamation District of Greater Chicago, Illinois • Fox River Water Reclamation District, Elgin, Illinois

Publications	Arabi, S., and E. Lynne. 2018. “Leveraging the Existing Infrastructure to Achieve Sidestream Enhanced Biological Phosphorus Removal and Energy Efficiency Upgrades.” WEF’s 91st Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC. Barnard, J.L. and E. Kobylinski. 2014. “Fundamentals of sludge fermentation for enhanced biological phosphorus removal.” WEF’s 87th Annual Technical Exhibition and Conference. New Orleans, Louisiana: WEFTEC. Barnard, J.L. and E.A. Kobylinski. 2018. “The Case for Side-Stream RAS or Mixed Liquor Fermentation to Enhance Biological Phosphorus Removal (EBPR).” Nutrient Removal and Recovery Conference. Raleigh, North Carolina: WEF. Barnard, J.L., D. Houweling, and M. Steichen. 2011. “Fermentation of mixed liquor for Removal and Recovery Phosphorus.” Nutrient conference. Downing, L., A.Z. Gu, P. Dunlap, and J.L. Barnard (in press). “Practices to Enhance Internal Fermentation of Side-Stream Secondary Sludge and Mixed Liquor Suspended Solids for Biological Phosphorus Removal.” Water Research Foundation Project 4975. Gu, A.Z., N. Tooker, A. Onnis-Hayden, D. Wang, V. Srinivasan, G. Li, E. Vargas, and I. Takács. 2014. “Optimization and Design of a Side-Stream EBPR Process as a Sustainable Approach for Achieving Stable and Efficient Phosphorus Removal.” Water Research Foundation (WRF) WRF ISBN: 978-1-60573-351-7. WRF Project Number: U1R13/4859. 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. Sabba, F., M. Farmer, Z. F. DiCapua, P. Dunlap, J. Barnard, C.D. Qin, J.A. Kozak, G. Wells, L. Downing. 2022. “Impact of operational strategies on a sidestream enhanced biological phosphorus removal (S2EBPR) reactor in a carbon limited wastewater plant.” Science of the Total Environment, 857, 159–280, 2023. Stroud, F. 2019. “S2EBPR Case Study—Full Scale Experience at South Cary Water Reclamation Facility 20 Years of Sidestream EBPR Process Operation.” Nutrient Removal and Recovery Symposium 2019. Tooker, N.B., L. Guangyu, V. Srinivasan, J.L. Barnard, C. Bott, P. Dombrowski, P. Schauer, A. Menniti, A. Shaw, B. Stinson, G. Stevens, P. Dunlap, I. Takács, H. Phillips, H. Analla, A. Russell, A. Lambrecht, J. McQuarrie, A. Onnis-Hayden, and A.Z. Gu. 2018. “Side-Stream EBPR Practices and Fundamentals -Rethinking and Reforming the Enhanced Biological Phosphorus Removal Process.” Nutrient Removal and Recovery Conference. Raleigh, North Carolina: WEF. Wang, D., N.B. Tooker, V. Srinivasan, G. Li, L.A. Fernandez, P. Schauer, A. Menniti, C. Maher, C.B. Bott, P. Dombrowski, J.L, Barnard, A. Onnis-Hayden, and A.Z Gu. 2019. “Side-Stream Enhanced Biological Phosphorus Removal (S2EBPR) Process Improves System Performance - A Full-Scale Comparative Study.” Water Research, Volume 167, December 15, 2019, 115109, https://doi.org/10.1016/j.watres.2019.115109 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: Carbon Addition 1410: Carbon Management
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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

Comparison of Sludge and RAS/MLSS Fermentation

While the intent of primary sludge fermentation and RAS/MLSS fermentation is similar, the two fermenters function quite differently. See comparison in Table 1.

Table 1. Comparison of Sludge and RAS/MLSS Fermentation.
Source: HDR Engineering, Inc.

Parameter	Primary Sludge	RAS/MLSS
Carbon source	Primary sludge: degradable particulate COD.	Biomass in BNR as RAS or as MLSS: If MLSS is fed after mixing with raw wastewater suspended BOD from raw wastewater is also a carbon source.
Fermentation process	Dedicated sludge fermentation in an enclosed, anaerobic basin. Fermentation also occurs in sludge thickeners in anaerobic conditions. Primary sludge and gravity thickener fermentation simply converts particulate BOD into rbCOD and VFA.	Typically implemented in a sidestream anaerobic zone. Use very low-intensity mixing to allow biomass to thicken and create low-ORP conditions, which simultaneously triggers PAO PO_4-P release and generation of rbCOD and VFA via hydrolysis and partial fermentation.
Biological reactions	Fermentation converting complex organics to VFA.	Fermentation of biomass produces rbCOD and VFA. The VFA produced is directly consumed by the active biomass/PAOs/glycogen-accumulating organisms (GAOs)/PHA-accumulating organisms within the same reactor and enhances EBPR. Some PAOs have been cited to have the ability to ferment.
Elutriation of fermentation products	Depends on the fermenter design. Natural circulation in basin can elutriate VFA; some fermenters include elutriation water to flush out VFAs.	Mixing intensity can be increased for short period to distribute rbCOD and VFA into the biomass for uptake and return the fermented biomass to the mainstream process.
Odor potential	High odor potential. Basins are typically covered and odor control is provided.	Much lower odor potential than sludge fermenter. Many basins are open to atmosphere; some are covered.
Cold/wet weather impacts	Dedicated fermenter is shielded from peak flows; however, the process of hydrolyzation begins in the collection system. Decreased HRT because of higher flows and lower temperatures will decrease the fermenter VFA output.	Fermentation zone is shielded from peak flows, but lower temperatures slow down reaction rates. Wakarusa performed well at 12°C, but lower temperatures slow down reaction rates. Batch testing has shown that the fermentation rate is decreased by 30% at temperatures of 10°C.
Grease	Because of its low pH, dissolved grease solidifies and can adhere to the pipe surface, plugging pipes over time.	Grease scaling is not an issue for RAS/MLSS fermentation. If insufficient mixing is provided, a scum layer can form on the top of the RAS fermentation tank.

Abbreviations

°C	Degree(s) Celsius
BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
COD	Chemical oxygen demand
EBPR	Enhanced biological phosphorus removal
GAO	Glycogen-accumulating organism
I&C	Instrumentation and controls
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
MLSS	Mixed liquor suspended solids
N	Nitrogen
NAS	Nitrifying activated sludge
NO_x	Oxidized nitrogen (nitrate + nitrite)
NutRem	Nutrient removal
O&M	Operations and maintenance
ORP	Oxidation-reduction potential
P	Phosphorus
PAO	Polyphosphate-accumulating organism
PHA	Polyhydroxyalkanoate
RAS	Return activated sludge
rbCOD	Readily biodegradable COD
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
S2EBPR	Sidestream enhanced biological phosphorus removal
SRT	Solids retention time
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
UFAT	Unified Fermentation and Thickening
UV	Ultraviolet
VFA	Volatile fatty acid
WAS	Waste activated sludge

WRF	The Water Research Foundation
WRRF	Water resource recovery facility