WRF 4973 Fact Sheet: ID 1121

Strategy: Process Intensification

Nutrient Removal in High-Purity Oxygen Process

Typical Covered HPO Basin with Mechanical Mixers/Spargers for Aeration.
Source: HDR Engineering, Inc.

Covered Mechanical Sparger in Opened Basin to Aerate with Pure Oxygen Supplied under Cover (Linde).
Source: Printed with permission from Linde, Inc.

Using high-purity oxygen (HPO) in the aeration system of an activated sludge process provides a high oxygen transfer rate into the liquid and can accelerate the biological reactions, especially when the wastewater contains high concentrations of readily biodegradable organics. The higher biological oxidation rate can result in significantly smaller bioreactors while effectively removing biochemical oxygen demand (BOD) from the liquid. These characteristics make this process attractive when treating certain industrial wastewaters with high soluble BOD or that contain volatile organics that require containment during treatment, require a small treatment footprint, and do not require nutrient removal. Large cities or industrial dischargers are good candidates for HPO treatment.

Nutrient removal can be achieved in an HPO treatment process by modifying the process and creating appropriate treatment conditions. These solutions can include the following: increasing the biomass to grow slow-growing organisms (e.g., nitrifiers), increasing aeration capacity to meet nitrification demand, sustaining a favorable pH in the bioreactor, and creating different environmental conditions to support nitrification, denitrification, and biological phosphorus removal, and others.

Structural and equipment modifications are typically required to change the secondary process to a nutrient removal process in existing HPO basins. Modifications could include some of the following:

- Increase bioreactor basin volume or repurpose tankage unused tanks now available because of reduction in planned industrial load
- Replace mechanical equipment to created anoxic and anaerobic zones
- Add internal recycle
- Seed with biomass from a parallel nutrient removal plant
- Vent headspace to reduce carbon dioxide (CO_2) in gas phase
- Change to air activated sludge
- Chemical addition
- Change process HPO aerator equipment; e.g., oxygen injection equipment

See the Additional Information section below about challenges and opportunities for achieving nutrient removal in HPO plants.

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

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

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	2	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 (https://www.waterrf.org/sites/default/files/file/2019-07/LIFT%20Scan%20Application-LIFT%20Link%2BHub_0.pdf : accessed September 2020)

Descriptions/Evaluation

Strategy	Converting an HPO process to achieve nutrient removal
Description	HPO processes are typically applied for BOD removal. In some cases, HPO may be staged with first-stage BOD removal and second-stage nitrification. Some HPO processes include anaerobic selectors to improve settleability but these also remove phosphorus. Because of the short retention times, HPO processes have a high waste activated sludge (WAS) production with very active biomass. The pH is normally depressed to between 6.0 and 6.5 because of dissolved CO_2 increase because of CO_2 accumulation with the closed headspace. The depressed pH reduces nitrifier growth rates.
Application	HPO processes are typically applied for BOD removal in a small footprint. These conditions apply when treating high-strength wastewater or locations with limited space for treatment facilities. The strategies in this fact sheet (see Additional Information section) focus on ways to achieve nitrogen removal biologically and phosphorus either biologically or chemically.
Constituents removed	Ammonium (NH_4), total nitrogen (TN), and total phosphorus (TP)
Development status*	The HPO process is a well-established process for BOD removal; very few HPO plants remove nutrients.
O&M considerations	The equipment for nutrient removal is well established. Pure oxygen generation equipment is more complex and requires specially skilled operators.
Benefits	Longer solids retention time (SRT) activated sludge processes will reduce solids production and produce a well oxidized, effluent water quality that will improve disinfection and tertiary treatment (if present).
Limitations	Depends on strategy.
Design considerations	The low pH and reduced SRT of HPO treatment processes needs to be overcome. Evaluation of treatment capacity based on modifications should be considered. The changes may reduce rated treatment capability of HPO.
Potential fatal flaws	None, as long as biological process remains stable.
Footprint requirements	Depends on strategy.
Residuals	Waste sludge production likely to decrease with increased SRT.
Cost considerations	Conversion from HPO to achieve nutrient removal will require some investment. The amount is dictated by the selected strategy.
Past experience	Site-specific. Ability to raise SRT and maintain favorable operational conditions is key to achieving nutrient removal.
Publications	Bonomo, L., G. Pastorelli, E, Quinto, and G. Rinaldi. 2000. Tertiary Nitrification in Pure Oxygen Moving Bed Biofilm Reactors. Water Science and Technology, 414–415, 361–368. Fabiyi, M., K. Connery, R. Marx, M. Burke, R, Goel, and S. Snowling. 2012. Extending the Modeling of High Purity Oxygen Wastewater Treatment Processes: Transition from Closed to Open Basin Operations - A Full Scale Case Study. WEFTEC Proceedings pp. 4, 250–254, 262. New Orleans: Water Environment Federation. Gilligan, T. P., and A.L. Morin. 1999. High Purity Oxygen Biological Nutrient Removal. NEWEA Journal, 331, 64–70. Neethling, J.B., C. Spani, J. Danzer, and B. Willey. 1998. Achieving Nitrification in Pure Oxygen Activated Sludge by Seeding. Water Science Technology, 374-5, 573–577. Randall, C. and E.U. Cokgor. 2001. Modification and Expansion of a Pure Oxygen WWTP for Biological Nutrient Removal (BNR). Water Science and Technology, 441, 167–172.

	Riska, R., J. Husband, P. Kos, and R. Johansen. 2004. Pilot Scale Tests of a Unique Approach for BNR Upgrade of a Short SRT High Purity Oxygen System at Pima County, Arizona. WEFTEC Proceedings pp. 258–284. New Orleans: Water Environment Federation. Sears, K., J. Oleszkiewicz, and P. Lagasse. 2003. Nitrification in Pure Oxygen Activated Sludge Systems. Journal of Environmental Engineering, 130–135.
Related fact sheets	1101: Process Intensification Overview 1110: Increase Biomass 1120: Nutrient Removal in Existing Secondary Process
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Additional Information

The use of pure oxygen for aeration in the HPO activated sludge process produces changes in the bioreactor environment that is counter to the process conditions required for conventional nutrient removal (CNR). The challenges are to:

- Increase the SRT to support nitrifiers growth and retention. Fact sheet 1110 contains some strategies to increase biomass in an activated sludge process. Many of these strategies could be considered for an HPO process.
- Raise the pH. The low pH in HPO plants (6.0–6.5) is the result of CO_2 accumulation in the gas phase as microorganisms oxidize BOD.
- Provide sufficient clarifier capacity to accommodate higher mixed liquor suspended solids (MLSS) associated with an increased SRT.

The pH limitation can be overcome by a high SRT (10–15 days) depending on temperature limitations. Nitrification may require a longer SRT with depressed pH in cold climates.

Strategies to Increase Biomass SRT in an HPO Process

The SRT in the HPO process can be increased to meet the reproduction rate of nitrifiers by increasing the biomass in the bioreactor. This can be achieved by reducing wasting, using step feed to raise the MLSS concentration in the bioreactor, or adding media carriers. The SRT can also be increased by seeding the bioreactor from another nitrifying activated sludge process.

Strategies to increase the biomass SRT in the biological basin are presented in Table 1. The increased SRT can support nitrification and could increase the solids loading to the clarifiers. Some additional considerations when increasing the biomass are the following:

- Evaluate aeration system. This could include continued use of pure oxygen or a change to a conventional aeration system (blowers and diffusers) to meet the change in oxygen demand to sustain nitrification. Include an assessment of the pH change associated with use of pure oxygen.
- Evaluate secondary clarifier capacity to receive and clarify the increased biomass loading.
- Evaluate wasting capacity—it may be oversized to accommodate the longer SRT.
- Evaluate operating environment/conditions (see next section).

Table 1. Strategies to Increase Biomass SRT in HPO Process.

Strategy	Description	Application Notes
Reduce wasting to raise SRT	Raise MLSS by reducing wasting.	The MLSS in the bioreactor can be increased provided that the secondary clarifier has capacity to accept the higher-concentration MLSS.
Operate in step-feed mode	Concentrate return activated sludge (RAS) in a reaeration zone to increase the aerobic biomass fraction to support nitrifier growth. MLSS in the contact zone is reduced with influent to reduce solids loading to the clarifier.	The MLSS in the bioreactor can be increased provided that the secondary clarifier has capacity to accept the higher concentration MLSS.
Add media (suspended integrated fixed-film activated sludge [IFAS])	Add suspended biomass carriers to retain biomass in the aerobic zone.	Screens to retain media can be limited by hydraulic head available across the basin.
Seed HPO process with nitrifiers	Provide a seed of nitrifiers from a nitrifying process. Seeding can be provided from: • A parallel nitrifying process (activated sludge or trickling filter) • Nitrifier seed grown on a dedicated reject water treatment process	The MLSS in the bioreactor can be increased provided that the secondary clarifier has capacity to accept the higher-concentration MLSS.

Strategies to Create an Environment to Sustain Nitrification in an HPO Process

The required SRT to nitrify in the HPO process can be reduced by creating favorable operating conditions in the bioreactor. The key environmental condition is pH.

CO_2 generated from BOD oxidation in an enclosed HPO bioreactor will elevate the dissolved CO_2(aq) concentration. CO_2(aq) is a weak acid that will lower to pH in the basin, typically into the low pH 6 range. The growth rate of nitrifiers decreases rapidly as the pH drops below 7.0, demanding a longer SRT to sustain nitrification.

Strategies to increase the pH in an HPO process include options to raise the alkalinity (by adding chemicals or denitrifying) or strip the CO_2(g) from the mixed liquor are presented in Table 2. Some additional considerations when applying strategies to raise the pH are the following:

- Some strategies reduce the aeration system oxygen transfer capacity and may require upgrades.

Table 2. Strategies to Raise the pH in the HPO Process.

Strategy	Description	Application Notes
Increase alkalinity by adding chemical	Add a base (sodium hydroxide, magnesium hydroxide, lime, or other) to raise the pH.	Chemical cost to raise the pH is typically very high and not attractive.
Isolate and open one HPO stage to strip CO_2	Stripping CO_2 is effective and cost-effective to implement.	Venting one HPO stage requires some investment and the process may lose some aeration capacity.
Change dissolution equipment to a partially covered floating hood	Change aerators to a floating hood to provide partial coverage for the HPO aeration. The partial cover traps the HPO while leaving open surface to strip CO_2 from the liquid.	Proprietary system is Praxair's In-Situ Oxygenation (I-SO™) System. Retrofitting the I-SO system into an HPO plan can provide nitrification with equipment substitution.
Change conventional air aeration system	Remove HPO equipment and replace with conventional aeration (diffused air or mechanical aeration).	Evaluate aeration capacity with alternative aerators to determine process capacity for nitrification (and denitrification/enhanced biological phosphorus removal [EBPR]) as required.
Convert bioreactor to nitrify and denitrify	Use a conventional biological nutrient removal (BNR) process for nitrification/denitrification such as modified Ludzack-Ettinger (MLE), step feed, or other CNR process. Denitrification will recover alkalinity and raise the pH.	Conversion may require internal recycle pumps, aeration system changes, WAS control, and other process control features.

References

Bonomo, L., G. Pastorelli, E, Quinto, and G. Rinaldi. 2000. Tertiary Nitrification in Pure Oxygen Moving Bed Biofilm Reactors. Water Science and Technology, 414-5, 361–368.

Fabiyi, M., K. Connery, R. Marx, M. Burke, R, Goel, S. Snowling. 2012. Extending the Modeling of High Purity Oxygen Wastewater Treatment Processes: Transition from Closed to Open Basin Operations—A Full Scale Case Study. WEFTEC Proceedings pp. 4,250–254,262. New Orleans: Water Environment Federation.

Gilligan, T. P., and A.L. Morin. 1999. High Purity Oxygen Biological Nutrient Removal. NEWEA Journal, 331, 64–70.

Neethling, J.B., C. Spani, J. Danzer, and B. Willey. 1998. Achieving Nitrification in Pure Oxygen Activated Sludge by Seeding. Water Science Technology, 374–375, 573–577.

Randall, C. and E.U. Cokgor. 2001. Modification and Expansion of a Pure Oxygen WWTP for Biological Nutrient Removal BNR. Water Science and Technology, 441, 167–172.

Riska, R., J. Husband, P. Kos, and R. Johansen. 2004. Pilot Scale Tests of a Unique Approach for BNR Upgrade of a Short SRT High Purity Oxygen System at Pima County, Arizona. WEFTEC Proceedings pp. 258–284. New Orleans: Water Environment Federation.

Sears, K., J. Olexzkiewicz, P. Lagasse. 2003. Nitrification in Pure Oxygen Activated Sludge Systems. Journal of Environmental Engineering, 130–135.

Abbreviations

BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CAS	Conventional activated sludge: BOD removal only
CNR	Conventional nutrient removal
CO_2	Carbon dioxide: (aq) = aqueous phase; (g) = gas phase
EBPR	Enhanced biological phosphorus removal
HPO	High-purity oxygen
I&C	Instrumentation and controls
IFAS	Integrated fixed film activated sludge process
I-SO	In-Situ Oxygenation
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
MLE	Modified Ludzack-Ettinger
MLSS	Mixed liquor suspended solids
N	Nitrogen
NAS	Nitrifying activated sludge
NH_4	Ammonium
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
SRT	Solids retention time
TDL	Technology Development Level
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
UV	Ultraviolet
WAS	Waste activated sludge
WRRF	Water resource recovery facility
WRF	The Water Research Foundation