WRF 4973 Fact Sheet: ID 1320

Strategy: Chemical Addition

Chemical Phosphorus Removal

Actiflo for Tertiary P Removal.
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Tertiary MBR with Chemical P Removal to Low Levels.
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Chemical phosphorus (P) removal is commonly practiced in nutrient removal water resource recovery facilities (WRRFs). The chemical use can be the main P removal method, as a backup for increased reliability and performance, or for polishing to reduce P to low concentrations. Chemical and biological P removal can be practiced in the same WRRF, but when this is done there appears to be a competition between the two for phosphate (soluble reactive phosphorus [SRP]).

Chemical addition for P removal is simple to implement and operate. The chemical feed facilities include chemical storage and feed facilities and a well-mixed dose point. Chemical dose can be controlled via many strategies, including maintaining a dose concentration, controlled to meet a target P concentration, or based on a chemical/P dose ratio. Common dose points at a WRRF are the primary clarifiers, secondary clarifiers, or other locations ahead of tertiary solids separation processes. Ferric can also be added to the collection system for odor control and to remove P. In addition, chemical addition to the reject water from dewatering operation will reduce the P loading to the WRRF and can eliminate undesirable struvite precipitants from forming.

A chemical hydrous metal oxides (HMO) sludge is produced when adding metal hydroxides to the water. Previously formed HMOs remain effective for a few days to form chemical bonds with SRP to remove P. This SRP removal reduces the additional chemical needed to remove phosphate in the liquid. It can also reduce the solids retention time (SRT) in dewatering reject water to prevent nuisance precipitants. Hydrous metal oxide sludge from water treatment plants that used alum or ferric can capture P in sewer transmission lines. Likewise, chemical sludge from tertiary application (i.e., filter backwash) can be directed to the influent to aid with both influent P sequestration and primary clarifier solids P removal.

At facilities with P recovery, HMO sludge generated by metal salts can reduce product yield by continuous sequestration of phosphates by the HMO sludge as it travels through the treatment process. A chemical such as cesium chloride may be better suited as backup for enhanced biological phosphorus removal (EBPR) in P-recovery facilities as it does not have the same P sequestration trail as conventional coagulants.

This fact sheet presents information on implementing or optimizing chemical addition for P removal. It contains information about chemical options, application points, and dose requirements.

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

Goal		
	R	Improve reliability
	R	Reduce nutrient
		Reduce O&M cost
Group	R	Optimize existing CNR
	R	Optimize existing TNR
	R	NutRem in secondary plant
Process	R	Small
	R	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 efficiency	3–5	Compared to conventional (1 = much less; 3 = conventional; 5 = much more)
O&M impact	3–5	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	1–3	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	Chemical phosphorus removal
Description	The purpose of chemical addition to sequester soluble orthophosphate (PO_4-P) as measured by SRP is to either supplement biological removal or serve as the sole means of P removal. Chemical addition to a reject stream is used to prevent nuisance precipitants (struvite) from forming.
Application	Adding chemicals (metal salts, lime, industrial waste products, or other) for P removal can occur at many places in a WRRF. Because the precipitants need to be removed, the common locations are typically ahead of solids separation processes such as primary clarifiers, secondary clarifiers, or tertiary clarifiers/filters. P removal can also be a by-product of other treatment goals such as: • Struvite control in EBPR systems where chemicals are added to the digester feed or upstream of dewatering to protect pipes and equipment from struvite scaling • Chemically enhanced primary treatment (CEPT) uses coagulants and polymer to increase particulate removal, which also removes a fraction of the influent soluble PO_4-P. • Ferric used for odor control will also sequester phosphate. • Ferric can be added to digesters to reduce phosphate recycle and will reduce odor (hydrogen sulfide [H_2S]) at the same time. • Some coagulants when fed upstream of dewatering will also improve dewaterability and lower the dewatering polymer dose. In EBPR WRRFs the impact can be significant and much of the coagulant chemical cost can be recovered by savings in dewatering polymer and hauling.
Constituents removed	SRP, which is primarily PO_4-P Sulfide (odor, corrosion)
Development status*	LIFT PDL 5
O&M considerations	Chemical use is most efficient where SRP concentrations are high, such as in the raw influent or recycle from digestion. Before chemicals are added to the mainstream process to lower effluent phosphorus, at least 80% of the recycle phosphorus should be sequestered. Some metal salts, like ferric and alum, form HMO precipitants that will continue to sequester phosphate through adsorption and complexation. Aluminum or ferric chemical sludge from a filter backwash or tertiary clarifiers can be recycled back to the liquid process (e.g., before primary clarifiers) or into reject water streams to remove SRP and reduce the P load to the secondary and tertiary treatment processes.
Benefits	Lower effluent P concentrations, more reliable treatment, and reduction of struvite nuisance precipitants Achieve multiple benefits by achieving odor control in sewers with ferrous addition to collection system for sulfide control. Iron sulfide is oxidized to ferric and sulfate under aerobic conditions in aeration basins and the ferric precipitates phosphorus (Salehin et al. 2019, Kulandaivelu et al. 2020).
Limitations	Particulate P capture is critical to removing P. In both biological and chemical P removal WRRFs, the effluent P concentration will be a function of particulate removal. Phosphate, SRP, can be reduced to near zero (1–2 micrograms [µg] P per liter [L]) but doing so requires the use of highly effective particle capture processes, such as microfiltration and ultrafiltration. Soluble non-reactive phosphorus (sNRP) is poorly removed with chemical addition and often remains in treated effluent.
Design considerations	• Most chemicals used are considered hazardous. Ferric is particularly corrosive. • Ensure that the receiving pipe or tank is compatible with the chemicals used.

	• Chemical cost varies regionally and may drive selection—systems should be designed to be compatible with several common P removal chemicals.
Potential fatal flaws	• Adding metal salts increases total dissolved solids (TDS). • Ferric addition can result in vivianite scaling. • Some chemicals consume alkalinity, which could impact nitrification and anaerobic digester operation.
Footprint requirements	Minimal
Residuals	Chemical sludge
Cost considerations	Consider continuous online dose control to optimize chemical use.
Past experience	WRRFs relying primarily on chemical P removal include City of Las Vegas (1991), DC Water, Coeur d'Alene, Spokane County (Washington) WRF
Publications	Dabkowski, B., R. Minnema, C. Korbe, and J. Burke. 2012. "Evaluation of an 'Off the Shelf' Automated Chemical Phosphorus Removal System." WEFTEC. Kulandaivelu, J., S. Shrestha, W. Khan, J. Dwyer, A. Steward, L. Bell, P. Mcphee, P. Smith, S. Hu, Z. Yuan, G. Jiang. 2020. Full-scale investigation of ferrous dosing in sewers and wastewater treatment plant for multiple benefits. Chemosphere, 250, https://doi.org/10.1016/j.chemosphere.2020.126221. Maher, C., J.B. Neethling, and K.R. Pagilla. 2013. "Operational Investigation of the Role of Precipitated Solids in Full Scale Tertiary Chemical P Removal From Wastewater Effluents." WEFTEC. Maher, C., J.B. Neethling, and K.R. Pagilla. 2014. "Solids Role in Tertiary Chemical Phosphorus Removal by Alum." WERF Nutrient Removal Challenge Report NUTR1R06t. Melcer, H., P. Heck, T. Lindley, A.N. Klein, M. Winkler, and B. Watson. 2016. "There's More to Chemical Precipitation for Phosphorus Removal than Meets the Eye." WEFTEC 2016 3526–3534. Neethling, J.B., D.A. Pivetti, B.E. Burris, and T. McCaffrey. 1991. "Chemical phosphorus removal in a trickling filter plant." WPCF 64th Annual Conference & Exposition, Toronto, October 7–10, 1991. Reardon, R., E. Stone, A. Conklin, and B. Graham. 2016. "The Costs of Phosphorus Removal—Chemical vs. Biological." Nutrient Conference. Salehin, S., J. Kulandaivelu, M. Rebosura Jr., W. Khan, R. Wong, G. Jiang, P. Smith, P. McPhee, C. Howard, K. Sharma, J. Keller, B.C. Donose, Z. Yuan, and I. Pikaar. 2019. Opportunities for reducing coagulants usage in urban water management: The Oxley Creek Sewage Collection and Treatment System as an example, Water Research 165, November 15, 2019, https://doi.org/10.1016/j.watres.2019.114996.
Related fact sheets	1101: Process Intensification Overview 1301: Overview of Chemical Addition 1630: Sidestream Phosphorus Treatment, Control, and Recovery
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Note

* Technology ranking based on LIFT 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)

Additional Information

Table 1 contains chemical properties for some of the most commonly used chemicals for P removal.

The molar dose ratio of metal salt/P to achieve a given target residual PO_4-P concentration increases as the target PO_4-P concentration decreases. This is depicted in Figure 1 for aluminum and in Figure 2 for iron/ferric.

Table 1. Common P Removal Chemicals.
Source: HDR Engineering, Inc.

Chemical Name	Chemical Formula	Active Chemical	Stock Concentration (% chemical)	Specific Gravity (-)	Alkalinity Consumption (lb $CaCO_3$/ lb chemical)	Sludge (lb TSS/ lb chemical)
Ferric chloride (ferric)	$FeCl_3$	Fe	40%	1.4	0.92	0.66
Ferrous sulfate (ferrous)	$FeSO_4$	Fe	14%	1.17	0.66	0.70
Alum	$Al_2(SO_4)_3$ 14 H_2O	Al	45%	1.3	0.51	0.26
Sodium aluminate	$NaAlO_2$	Al	20%	1.46	Increase	1.5
PACl or PAX	Proprietary	Al	32%	Varies	Varies	Varies
Lime	$Ca(OH)_2$ as $CaCO_3$	pH hydroxide	Varies	Varies	Increase	Varies
Cerium	$CeCl_3$	Ce	32%	1.48	N/A	N/A
Pickle liquor	$FeCl_3$	Fe	Varies	Varies	Varies	Varies

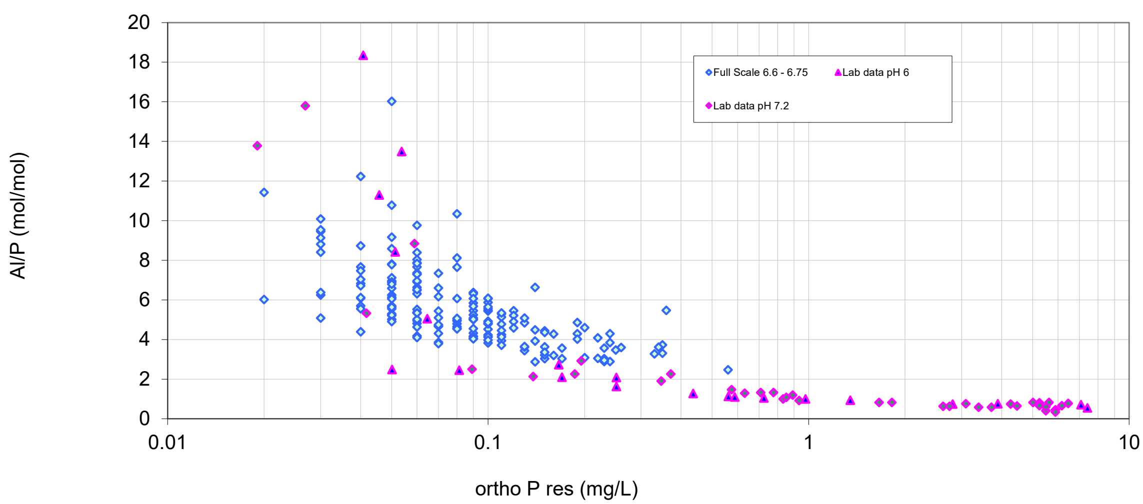

Figure 1. Aluminum/P Molar Ratio vs. PO_4-P Residual.
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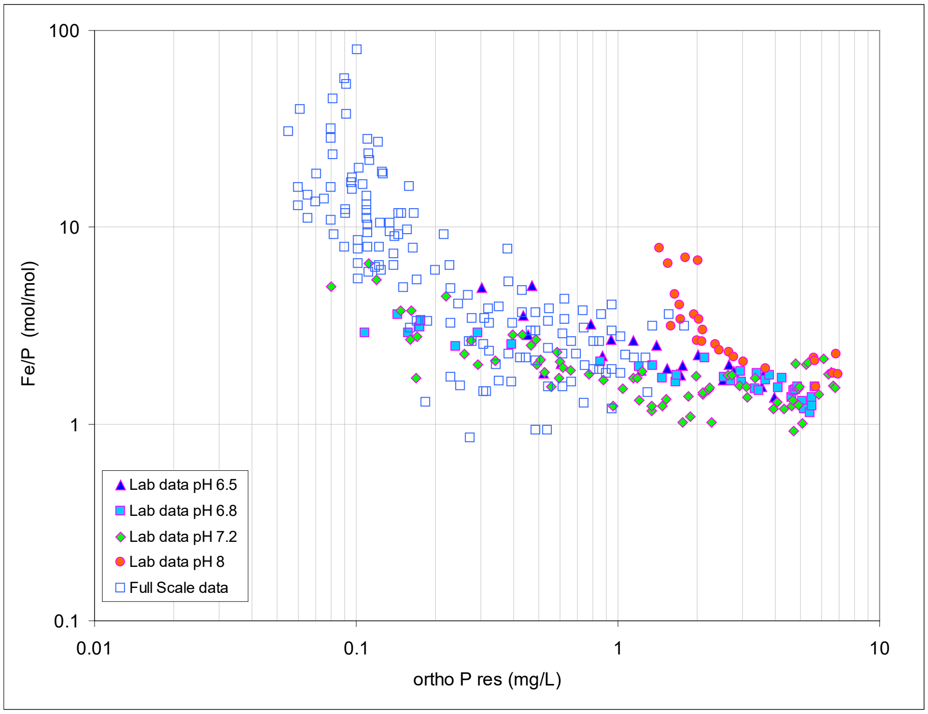

Figure 2: Ferric/P Molar Dose vs. PO_4-P Residual.
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Abbreviations

µg	Microgram(s)
BOD	Biochemical oxygen demand
$CaCO_3$	Calcium carbonate
CAS	Conventional activated sludge: BOD removal only
CEPT	Chemically enhanced primary treatment
CNR	Conventional nutrient removal
EBPR	Enhanced biological phosphorus removal
H_2S	Hydrogen sulfide
HMO	Hydrous metal oxides
I&C	Instrumentation and controls
L	Liter(s)
lb	Pound(s)
LIFT	Leaders Innovation Forum for Technology (now RIC and RISE)
mgd	Million gallons per day
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
PACl	Polyaluminum chloride
PAX	A proprietary of the PACl family
PO_4-P	Orthophosphate
RIC	Research & Innovation Committee
RISE	Research and Innovation for Strengthening Engagement
sNRP	Soluble non-reactive phosphorus
SRP	Soluble reactive phosphorus
SRT	Solids retention time
TDL	Technology Development Level
TDS	Total dissolved solids
TN	Total nitrogen
TNR	Tertiary nutrient removal
TP	Total phosphorus
TSS	Total suspended solids
UV	Ultraviolet
WRF	The Water Research Foundation
WRRF	Water resource recovery facility