What Every Operator Needs to Know About Phosphorus Removal

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Knowledge	Principle	Practical Considerations
Why is phosphorus removed from wastewater?	Excess phosphorus can fuel algal blooms that degrade surface water quality for drinking water, marine life, and recreation.	Water resource recovery facility (WRRF) discharges can be a significant source of phosphorus in surface water. Therefore, removing phosphorus from wastewater can improve surface-water quality.
Phosphorus regulations	The U.S. Clean Water Act prohibits the discharge of pollutants to federally designated "Waters of the U.S." without a National Pollutant Discharge Elimination System (NPDES) permit. NPDES permits are issued by the U.S. Environmental Protection Agency (EPA) or by states with delegated authority.	NPDES permits can incorporate effluent phosphorus limits in several different ways. These may include, for example, by concentration and/or mass (daily, monthly, annual); or numeric limits based on water quality standards, impaired water body classifications, total maximum daily loads, and/or waste load allocations.
Forms of phosphorus in wastewater	Phosphorus can be categorized into two main forms: soluble and particulate. Each of these forms can be further subcategorized into reactive and nonreactive.	Phosphorus-removal methods convert the soluble reactive phosphorus into particulate form through chemical reaction with metal salts or incorporating into the biomass, which then can be removed through physical separation processes like settling and filtration. Soluble nonreactive organic phosphorus does not react with chemicals (metal salts) or is not available for biological uptake. Therefore, it is discharged with the effluent.
Phosphorus analyses	Water professionals can test for total phosphorus through a digestion test method (to convert particulate and colloidal reactive phosphorus into soluble reactive phosphorus) and a colorimetry process (to measure soluble reactive phosphorus). Using a wet chemistry analyzer can achieve real-time facility monitoring of orthophosphate (soluble reactive phosphorus).	Detailed phosphorus testing is lab-intensive and requires special equipment, but it is important in running a phosphorus-removal process to monitor the phosphorus profile (where) and species (what form) throughout the WRRF.

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Chemical addition for phosphorus removal	Metal salts are added to precipitate soluble reactive phosphorus, and precipitates are removed with solids through physical separation processes.	Chemical precipitation is an effective, immediate solution for phosphorus removal. It can offer a range of benefits. • It enables technicians to apply chemicals prior to the primary sedimentation process, with further removal occurring in later processes. • Chemical precipitation can serve as a tertiary polishing step, or a backup/simultaneous process with biological phosphorus removal. • Chemical precipitation avoids the re-release of phosphorus in anaerobic solids processing that is typically observed during biological phosphorus removal. This re-release can lead to potential struvite issues and recycling of phosphorus to the treatment process. • Minimum equipment needed includes a storage tank, metering pump (such as solenoid or peristaltic or diaphragm type), and tubing.
Chemical selection	Metal salts containing cations of aluminum (typically alum), iron (typically ferric chloride), calcium, and magnesium can be used for chemical phosphorus removal. Several proprietary formulations for phosphorus removal have been marketed in recent years whose composition is typically unknown.	Chemical selection should consider availability, chemical-handling hazards, storage requirements, and cost. Metal salts can accumulate over time and coat the ultraviolet lamp sleeves, thereby reducing ultraviolet transmittance and disinfection efficiency. Additionally, iron-based salts (specifically Fe^{3+}) can interfere with ultraviolet light and reduce disinfection effectiveness. Residual iron concentrations (< 0.5 mg/L as Fe) are recommended. Some facilities also have discharge limitations on metal salts.
Additional impacts of chemical removal	While phosphorus precipitation is a targeted result, adding chemicals may have other impacts on treatment.	Use of a metal salt coagulant typically will result in a reduction in alkalinity. It may reduce pH as well, if wastewater alkalinity is low. For example, alum consumes 0.5 mg/L alkalinity per mg alum applied. Adding metal salt to the secondary process will also decrease the ratio of mixed liquor volatile suspended solids (MLVSS) to mixed liquor suspended solids (MLSS). Thus, it may necessitate modifying wasting to maintain a consistent "active" solids age. Adding chemicals for phosphorus removal also will increase solids.
Chemical addition points	Selecting the correct chemical addition points will allow for efficient chemical use, good mixing, and prevent interference with biological treatment. Side streams with high phosphorus concentrations are an ideal target for chemical addition.	Dosing too much chemical can compete with biological treatment — and thanks to recycle streams, this happens even if the chemical is dosed downstream of biological treatment. If utilized for mainstream phosphorus removal, technicians can add coagulants at any point during the secondary process or in the center well of the final clarifier. Most applications take place in the final 10% of the aeration basin. Location considerations include proximity to the chemical storage tank and feed pump, mixing conditions, alkalinity, pH, and temperature (e.g., freeze potential). Dosing can be targeted in high-phosphorus side streams, such as the decant from an anaerobic digester, to target more phosphorus removal with a lower chemical dose. Side-stream treatment to reduce phosphorus recycle to the liquid stream can concurrently produce a marketable product, which can help offset treatment costs.

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Chemical dose determination	Chemical dose is a function of the chosen chemical, the starting and target phosphorus concentrations, forms of phosphorus, and the dosing location. At higher target phosphorus concentrations (> 1 mg/L), chemical dosing requires approximately 1 mol of added metal salt (alum or ferric) per mol of phosphorus removed. Chemical dose increases significantly (by severalfold) for target phosphorus concentrations less than 1 mg/L.	In a mainstream application, chemical dose can be reduced over time as the chemical concentrations increase in the MLSS due to recycle. Excess metal doses can negatively affect biological activity. For example, studies show that excess alum can reduce nitrification activity. Jar testing may assist in chemical dose determination.
Chemical solids quantity and consideration	Chemical solids are generated as part of chemical phosphorus removal. Chemical solids increase the total residuals generated by 10% to 20% and must be captured and managed as part of the overall solids processing approach.	Depending on the chemical used, theoretical estimations indicate between 8 and 20 kg of chemical sludge generation for every kg of soluble reactive phosphorus removed. The chemical solids generated may improve dewaterability.
Biological phosphorus removal	Process by which phosphorus-accumulating organisms (PAOs) provide enhanced biological phosphorus removal as part of water reclamation.	Biological phosphorus removal, while centered on the secondary treatment process, must be integrated as a facility-wide system.
Microbiology of biological phosphorus removal	PAOs and glycogen-accumulating organisms (GAOs) are the key microorganisms impacting biological phosphorus removal. PAOs incorporate phosphorus in their cells, which then is removed via the waste-activated solids. GAOs may compete with PAOs for resources without removing phosphorus.	It is important for operators to create an environment that favors PAO growth. This includes lower solids retention times to favor PAOs when wastewater temperature is above 20°C to 30°C (68°F to 86°F) or pH is below 7. Low ORP/fermenting conditions also are indicated to favor PAOs.
Process requirements for biological phosphorus removal (selectors)	Biological phosphorus removal requires alternating anaerobic and aerobic conditions, as well as sufficient biochemical oxygen demand (BOD), MLSS inventory, and mixing.	Selector designs target anaerobic conditions with a high food-to-microorganisms ratio, which are associated with PAO growth. A final aerobic phase of treatment is required for PAOs to uptake and store phosphorus prior to wasting. The BOD to total phosphorus (BOD:TP) ratio is a key operational parameter for biological phosphorus, because it reflects the availability of organic carbon relative to phosphorus, which is critical for PAOs to thrive. Traditionally, it is understood that PAOs rely on VFA uptake; however more recent research shows that PAOs may use other carbon sources. BOD:TP ratios of 20:1 to 25:1 are effective for good biological phosphorus removal performance. Presence of nitrite and nitrate or dissolved oxygen in the anaerobic selectors hinders PAO growth and phosphorus release.
Biological phosphorus removal impacts on solids handling	Waste solids from biological phosphorus removal release orthophosphate and magnesium in anaerobic conditions (e.g., anaerobic digestion). This results in reduced dewaterability and increased potential for struvite formation problems.	Manage waste solids with metal salts to bind phosphate, dilute side streams, manage side-stream pH, use or increase flushing to manage buildup, and implement phosphorus release prior to digestion.

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Emerging technologies for biological phosphorus removal	Several emerging technologies (such as granular activated sludge and waste-activated sludge cyclones) select for dense flocs, which increases the concentration of PAOs in the MLSS.	These technologies can be good options to achieve phosphorus removal with a lower footprint, or in some retrofit scenarios for biological phosphorus.
Redundancy and reliability	Biological phosphorus removal depends on specific microbiology and conditions that can be susceptible to upset. Therefore, redundancy needs to be considered when trying to meet effluent limits.	Most biological phosphorus facilities also include chemical phosphorus removal capabilities as a backup. Whether the effluent limit is mass- or concentration-based, as well as annual or monthly average, will dictate the redundancy required to meet the effluent limit consistently.
Instrumentation and automation	Real-time analyzers and sensors can improve monitoring and automated control of phosphorus removal systems.	Install online orthophosphate analyzers at key process locations, such as in effluent or anaerobic tanks. Use instrumentation such as dissolved-oxygen and oxidation-reduction-potential (ORP) probes to monitor anaerobic, anoxic, and aerobic zones for process control based on your facility's established ORP ranges. Typical ORP ranges: anaerobic (-250 to -100 mV); anoxic (+50 to -100 mV); aerobic (+50 to +350 mV). However, there could be exceptions for lower and upper values. Integrate instruments with supervisory control and data acquisition systems for data logging and alarm management. Calibrate sensors regularly and validate readings with lab data to maintain accuracy. Trend data to identify anomalies early on and make proactive process adjustments.
Operator decision-making in permitting context	Operator actions directly affect compliance with phosphorus limits set in discharge permits.	Track daily influent/effluent phosphorus concentrations and compare against permit limits. Adjust chemical dosing and wasting based on process data and performance trends. Ensure adequate BOD is available and supplement if necessary. Volatile fatty acid dosing and/or biomass fermentation may improve performance. Maintain detailed operational logs and justifications for changes affecting phosphorus removal. Coordinate with compliance managers to anticipate exceedance risks and document corrective actions. Train operators on permit limits and how process-control decisions affect regulatory compliance.

Useful Resources: For additional information and explanation on nutrient removal, please see *WEF Manual of Practice 34 — Nutrient Removal*. Additional information on phosphorus removal is available in *WEF Manual of Practice 37 — Standards for the Operation of Nutrient Removal Facilities* (chapters 7–9), while chapter 10 covers combined nitrogen and phosphorus removal systems.

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