EVOQUA
WATER TECHNOLOGIES

Phosphorous Management in Wastewater Treatment

USING ADVANCED TREATMENT OPTIONS TO MAKE THE MOST OF A VALUABLE RESOURCE

As is widely known, phosphorous is an essential nutrient for all forms of life, performing a vital role in the operating functions of animal plant and microbial cells. As such, it's a key component of the fertilizers we use in gardens, on golf courses, and, perhaps most importantly, on crops.

However, in the wrong place—the lakes and streams of our watersheds—too much phosphorous can be an environmental hazard, stimulating excess growth of algae and aquatic plants, which in turn deplete oxygen needed by fish and other aquatic life. According to the EPA, nutrient impairment prevails in 58% of the nation's rivers and streams, 45% of our lakes, about two thirds of our coastal areas, and more than one third of our estuaries.[1]

TOO MUCH OF A GOOD THING

We've all seen the effects of nutrient impairment in waterways in the late summer. High levels of nitrogen and phosphorus can cause eutrophication, which can lead to hypoxia ("dead zones"), causing fish kills and a decrease in aquatic life. Excess nutrients can cause harmful algal blooms (HABs) in freshwater systems, which not only disrupt wildlife but can also produce toxins harmful to humans and animals. Closed beaches, hazardous waters and dying fish are all the result of too much of a good thing.

Nutrients enter the watershed from a variety of sources. Non-point sources include runoff from farms, parks, golf courses and lawns that use phosphorus-rich fertilizers. Phosphorus-containing manure from livestock and wildlife, as well as inadequate septic systems also add to the non-point waste stream. Because phosphorus is present in significant amounts in human waste and, to a lesser extent, household detergents, wastewater discharge is one of the most significant point sources of phosphorus in the watershed.

As nutrient impairment of lakes and streams rises, municipalities and government agencies across the country are evaluating policies and options for reducing the amount of nutrients, including phosphorus, that enter the environment from all sources, including treatment plants. Permitted levels are decreasing year after year. At the same time, because phosphorus has high value as fertilizer, and is a limited natural resource, new options are emerging for recovering it from the waste stream and returning it to service in agriculture.

This white paper is written for engineers and operators of wastewater treatment plants who are facing changing phosphorus limits and exploring options for meeting the current and future environmental needs of their communities.

TIGHTER PHOSPHORUS LIMITS ARE COMING

Across the U.S., more and more treatment plants are facing permitted phosphorus limits as low as 0.05 mg/l or less. "According to the most recent EPA Integrated Compliance Information System (ICIS), approximately 29% of municipal wastewater treatment plants of 1 MGD or larger have either phosphorus only or phosphorus and nitrogen limits. And for small plants, which make up the vast majority of total number of facilities, less than 10% have discharge limits for P or N and P. However, this is changing rapidly as the EPA implements its strategy to accelerate nutrient pollution reduction in our nation's waterways. While much of this strategy involves addressing non-point source pollution, there will also be increased efforts to further reduce nutrient loads from point sources. The EPA has made clear their commitment to working with

[1] 2022 EPA Nutrient Reduction Memorandum

states and regional permitting authorities to issue new water quality-based permits. This initiative will result in more and more POTWs across the US facing new phosphorus limits, some as low as 0.05 mg/l or less. In addition to municipal wastewater plants, the EPA will be promulgating revised effluent limitation guidelines for industries".[2, 3]

While new facilities are often designed for, among other things, low phosphorus discharge; existing facilities that predate the current regulatory environment were not. Planners are looking for the best ways to upgrade their facilities for the lowest possible lifecycle cost.

PHOSPHOROUS IN WASTEWATER

Municipal wastewater typically contains between 4–8 mg/l of total phosphorus, present primarily in soluble form, as phosphate compounds. About half is present as orthophosphate and close to 40% as polyphosphate, a string of phosphate molecules. The remainder is present as organically bound phosphorus.[4]

Treatment system designers draw on five available technologies for removing these phosphates: chemical removal, biological removal, ballasted clarification, filtration and phosphorus recovery. Depending on plant configuration, projected growth, site limitations and regulatory requirements, an effective solution for meeting lower phosphorus requirements will most likely employ a combination of these technologies.

CHEMICAL REMOVAL: RELIABLE AND TIME TESTED

Chemical removal of phosphorous from wastewater is a proven, reliable and relatively economical process. It primarily uses aluminum, iron coagulants or lime to form chemical flocs with phosphorus. These flocs are then settled out to remove phosphorus from the wastewater.[5]

Me_{dose}/P_{ini} Ratio

- Mole ratio holds true when effluent P is greater than 1 mg/L
- Stoichiometric doses
  - Ferric dose of 1.8 g Fe per g P
  - Alum dose of 0.8 g Al per g P
- Me_{dose}/P_{ini} ratios of 1.5–2.0 are needed to remove 80–98% of soluble P
- Me_{dose}/P_{ini} ratios of 6–7 are needed to get below 0.10 mg/L

Dosing guidelines for chemical phosphorous removal.[6]

Chemical removal is a complex process with competing reactions that can vary with pH, alkalinity, reaction time and mixing intensity. It is often a multipoint process. Phosphorus occurs in several different forms throughout the wastewater process, and understanding its distribution is vital to monitoring and removal. Chemicals are frequently added at both primary and secondary stages, and tertiary treatment is used in plants that have ultra-low phosphorous level requirements.

Total Suspended Solids:

- 1 mg/L iron dosage = 1.9 mg/L TSS
- 1 mg/L aluminum dosage = 2.9 mg/L TSS

$$Al_2(SO_4)_3 \cdot (14H_2O) + 2H_2PO_4^- + 4HCO_3^- \rightarrow 2AlPO_4 + 4CO_2 + 3SO_4^{2-} + 18H_2O$$
$$FeCl_3 \cdot (6H_2O) + H_2PO_4^- + 2HCO_3^- \rightarrow FePO_4 + {}_3Cl^- + 2CO_2 + 8H_2O$$

Chemical removal is based on these aluminum- and iron-based reactions.

[2] EPA's April 5, 2022 Memorandum on Accelerating Nutrient Reduction in Our Nation's Waters
[3] EPA NPDES information
[4,5] EPA Design Manual on Phosphorous Removal
[6] Water Environment Federation Webinar – "Basics of Phosphorus Removal and Operational Lessons Learned, by the WEF Plant Operations and Maintenance Committee"

Volatile Suspended Solids:

- 1 mg/L iron hydroxide = 0.25 mg/L TSS
- 1 mg/L aluminum hydroxide = 0.35 mg/L TSS
- Affects digester VSS destruction

Typical yields. Successful removal ultimately depends on how well the process removes total suspended solids (TSS).

BIOLOGICAL PHOSPHOROUS REMOVAL: LOWER COST, LESS SLUDGE

In conventional biological treatment, phosphorus is removed as a normal part of aerobic biological growth. The microorganisms are then separated from the wastewater by settling or filtration. The biological yield of this process is approximately 0.5 lb. per pound of BOD removed, with phosphorous content of about 2% by weight.

Under typical conditions, the process will yield the following:

- Typical WW with 60 g BOD/cap/d, 1.5–2 gr P/cap/d, 0.3 m^3/cap/d = 200 mg/L BOD, 6.7 mg/L P, 30:1 BOD:P

Assimilative uptake of P

- Yield = 0.5 mg VSS/mg BOD, 2% P, 2 mg/L removed (30–40% removed)
- Effluent P = 3–4 mg/L

ENHANCED BIOLOGICAL PHOSPHOROUS REMOVAL: LOWER COSTS AND SUPERIOR EFFLUENT QUALITY

Enhanced Biological Phosphorous Removal (EBPR), in which the series of reactor processes are optimized for high-efficiency phosphorous removal, can increase the biomass content of waste sludge to 3–6% phosphorus compared to conventional activated sludge systems (normally 1.5–2%) Under the right conditions (generally, a BOD:P ratio of 30:1 with anaerobic/aerobic cycling of biomass), EBPR can reduce or completely eliminate the need for chemical precipitation or filtration, achieving effluent phosphorous levels below 1 mg/L or even < 0.3 mg/L on its own.

EBPR can be achieved in continuous flow systems or batch systems. Continuous processes such as Orbal®, VLR® and Bio-Nutre systems can be designed with an aerated-anoxic zone with a strong oxygen deficit. In other cases, the addition of an anaerobic selector can be used. An SBR can be operated with a static fill step at the beginning of treatment to create a strong reducing environment. In each case, by sequencing the biomass through a sufficiently anaerobic stage, and with a sufficient food source, prior to the reintroduction of oxygen, it is possible to selectively grow a biomass capable of storing phosphorus at a higher than conventional level. The phosphorus is ultimately removed from the system by settling and removing sludge.

Either method can be effective in reducing treatment costs and optimizing the process to achieve superior effluent quality. As in any biological system, the processes can be negatively impacted by flow and temperature variations as well as shock loads, so a backup chemical precipitation system should be considered to ensure consistent performance.

Considerations When Designing for EPBR:

- In the Orbal® system from Evoqua, a small anaerobic selector with mechanical mixer has been used successfully to enhance P removal in 2-channel systems and when a very low DO or ORP level cannot be maintained in the first channel. Orthophosphate levels in this selector have been observed to rise to levels of 30–40 mg/L as PO_4. The first anaerobic selector has also been used in systems requiring both low TN and TP levels to allow the anaerobic and aerated-anoxic environments to be optimized independently.
- In the OMNIFLO® SBR system from Evoqua, a static fill period can be added as the first treatment step,

OMNIFLO SBR systems accomplishes equalization, aeration, and clarification in a timed sequence in a single reactor basin providing a treatment process to support efficient biological nutrient removal (BNR) of ammonia nitrogen, total nitrogen and phosphorus.

At the Huntertown, Indiana Wastewater Treatment Plant, Evoqua's Orbal® system was designed for 1.5 MGD with three reactors in series to support simultaneous nitrification-denitrification (SND) and meet an average phosphorus (P) removal limit of 0.44 mg/L.

followed by mixed anoxic, aerated fill, and react steps. The static fill provides excellent conditions for fermentation, volatile fatty acid uptake, and phosphorus release. Subsequent anoxic and aerobic steps allow for uptake of phosphates.

- Experience with the Orbal system and OMNIFLO SBR systems show that increasing wasting rates can elevate sludge production rates above normal and increase biological production for best phosphorus removal. A young sludge will result in better phosphorus removal compared to older sludges (high MLSS) that contain more dead cells.
- Proper design and operation of the final clarifiers is essential to enhanced biological phosphorus removal. To minimize the risk of high effluent phosphorus, the sludge retention time (SRT) within the final clarifier should be less than 30 minutes. This is accomplished by using higher recirculation rates and a suction sludge removal device and maintaining a low or zero (less than 1 ft) sludge blanket. SBR settings can limit the length of settle and idle times to minimize phosphorus release.
- If discharge permits require phosphorus limits less than 1.0 mg/L, tertiary solids removal (filtration) may be necessary.
- When both phosphorus and nitrogen removal are required at a plant, some design and operating parameters required to achieve these goals conflict with each other. To effectively operate both processes, it is necessary to maintain tight control over operating parameters. Evoqua's PLC-based SmartBNR™ process control system is recommended for this purpose.
- Anaerobic digestion is generally incompatible with EBPR. Digester supernatants have very high soluble phosphorus. If EBPR is used in a plant with anaerobic digestion, it is usually necessary to chemically treat the digester supernatant to precipitate the soluble phosphorus. However, EBPR waste sludge does offer an opportunity for phosphorus recovery, as discussed below.

CLARIFIER ENHANCEMENTS AND TERTIARY TREATMENT: BALLASTED CLARIFICATION AND DISC FILTRATION

Ballasted clarification dramatically increases biological treatment capacity, helping to meet enhanced nutrient removal (ENR) limits and produce effluent quality far superior to conventional alternatives, and at lower life-cycle costs. Ballasted clarification uses a high-density inert material such as microsand or magnetite —fully inert iron ore particles—to ballast biological floc or conventional chemical floc, enhancing settling rates and increasing the performance of wastewater and water treatment facilities, while substantially reducing costs to upgrade process performance. The ability to handle a wide variation in flows and loads minimizes the risks of upsets.

BioMag® System: Ballasted Clarification for Biological Processes

Evoqua's innovative BioMag system uses magnetite to deliver the world's fastest proven settling clarification technology for biological floc, allowing capacity expansion and performance improvement with minimal plant modifications at the lowest cost possible. It consistently achieves a sludge volume index (SVI) of less than 50. The BioMag system is applied to activated sludge systems, providing up to 300% more treatment capacity in existing tankage.

CoMag® System: Ballasted Clarification for Chemical Processes

Evoqua's CoMag system is an innovative technology that infuses magnetite as a weighing agent into traditional chemical floc to efficiently reduce the total phosphorus (TP) levels far below that of conventional treatment. The CoMag system settles floc up to 30 times faster than conventional treatment, enabling plants to increase capacity and clarifier performance. It can reduce total phosphorus down to 0.05 mg/L and can achieve UV transmittance greater than 75% when integrated into any type of coagulation/flocculation process or clarifier.

Disc Filtration

Evoqua's Forty-X® Disc Filtration systems provide a solution to meet low level phosphorus effluent requirements by removing particulates associated with phosphorus. Designed with a unique woven optimum tertiary mesh (OTM) filter panel, the Forty-X Disc Filter uses an inside-out flow pattern for high-quality tertiary filtration.

In lieu of relying on gravity settling of chemical phosphorus flocs, the Forty-X actively filters floc particles out of the effluent stream.

Effluent from a WWTP's secondary solid-liquid separation process is blended with aluminum or iron coagulants in a rapid mix tank. The development of chemical phosphorus flocs is then grown into larger

Ballasted clarification systems dramatically increase biological treatment capacity, helping meet ENR limits and produces effluent quality far superior than conventional alternatives, and at lower life-cycle costs.

floc via polymer dosing and mixing in a flocculation tank before feeding into the disc filter system. Due to their large size, these floc particles are easily filtered removing a large percentage of post-biological process residual phosphorus. An effective biological treatment process in conjunction with phosphorus removal polishing via a disc filter can meet even the most stringent discharge permits.

ADVANCED PHOSPHORUS RECOVERY

With new phosphorous recovery technology from Ostara Nutrient Recovery Solutions and Evoqua, waste treatment facilities can do more than meet new lower limits for phosphorous: they can recover this valuable resource and return it to service as fertilizer.

Ostara's Pearl® system by Evoqua is a fluidized bed reactor that recovers phosphorous and ammonia from high strength nutrient streams that include sludge, dewatered liquor, and WAS thickening liquors. Within the Pearl system reactor, the growth of struvite (magnesium ammonium phosphate) is facilitated by the addition of magnesium in a controlled pH setting. This allows nutrients to crystallize into fertilizer granules which are harvested, dried and then distributed and sold by Ostara as Crystal Green® Fertilizer. The treated effluent is then discharged from the top of the reactor and returned to the plant with significantly reduced nutrient content.

Ostara's WASSTRIP® system releases phosphate from the waste activated sludge (WAS) produced in an enhanced biological phosphorous removal process. Subsequent sludge thickening diverts released phosphate into thickening liquor, which is then fed back to the Pearl system for nutrient recovery. The process tackles struvite issues, improves dewaterability and reduces biosolids production.

NOW IS THE TIME TO INVEST IN A GREENER FUTURE ... IN THE RIGHT PLACES

Society is battling nutrient impairment, of which phosphorous is a key culprit, on all fronts to reduce its impact on waterways and aquatic life. New farming practices, stormwater and runoff management, phosphate-free detergents, and other tactics are helping accelerate the progress of nutrient management.

The Bipartisan Infrastructure Law enacted in 2021 provides new opportunities for many communities to invest in clean and safe water, with the potential to accelerate progress on nutrient pollution even further. In this environment, wastewater treatment plant operators and designers have new resources for putting technologies like chemical removal, EBPR, and tertiary treatments to work to keep phosphorous in green spaces and farms where it can foster growth… and out of our watersheds, where it can be simply too much of a good thing.

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