



Phosphorus Treatment and Removal Technologies

Municipal
Division
Wastewater
Program

Introduction

While chemical and biological phosphorous treatments are the two main techniques for removing phosphorus from domestic and industrial wastewater, many variations and combinations have been used. The following is intended to provide a basic overview of basic phosphorous removal processes.

Chemical Treatment to Remove Phosphorus

Chemical treatment for phosphorus removal involves the addition of metal salts to react with soluble phosphate to form solid precipitates that are removed by solids separation processes including clarification and filtration. The most common metal salts used are in the form of alum (aluminum sulfate), sodium aluminate, ferric chloride, ferric sulfate, ferrous sulfate, and ferrous chloride.

Chemical treatment is the most common method used for phosphorus removal to meet effluent concentrations below 1.0 mg/L.

Chemical Treatment Design Components

Less complicated than biological approaches, the chemical treatment design approach consists of a mass balance between chemical addition, the stoichiometry of the chemical added and phosphorus removed, and the phosphorus concentration after chemical addition.

Chemical addition should be evaluated for two scenarios:

1. *Effluent polishing in the secondary process:* The chemical addition point is in the secondary treatment process to the mixed liquor stream just before the secondary clarifier.
2. *Two-point chemical addition (see Figure 1):* Chemical is applied in both the primary clarifier feed and also just before the secondary clarifier. Two-point addition is popular for many applications because it achieves the most efficient use of chemicals for phosphorus precipitation.

Contents:

Chemical treatment to remove phosphorus	1
Enhanced biological phosphorus removal (EBPR)	2
Critical factors for the success of EBPR	3
Sources	5
For more information	5

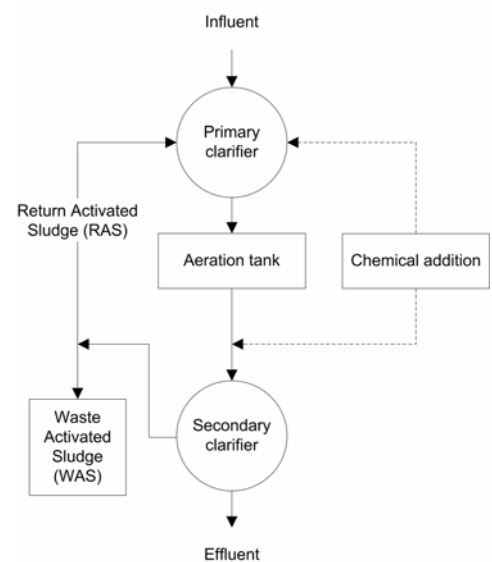


Figure 1. Two-point chemical addition

Chemical Dose

The required chemical dose is related to the liquid phosphorus concentration. For target concentrations above 2 mg/L (appropriate for chemical addition to a primary clarifier), a dose of 1.0 mole of aluminum or iron per mole of phosphorus is sufficient. For lower phosphorus concentrations in the range of 0.3 – 1.0 mg/L, the dose can be in the range of 1.2 to 4.0 moles aluminum or iron per mole of phosphorus. The pH value is an important factor for efficient removal of phosphorus using alum or other salts, as the solubility of their precipitates vary with pH. Phosphorus removal is most efficient in the pH range of 5 to 7 for alum and of 6.5 to 7.5 for ferric salts since their precipitates will not readily return to solution.

Sludge Production

With chemical addition, sludge production will increase in the wastewater treatment unit process where the chemical is applied. Sludge production has been noted to increase by 40 percent in the primary treatment process and 26 percent in activated sludge plants.

Capital Costs

Generally, the capital costs of chemical removal systems are lower than that of enhanced biological phosphorus removal (EBPR) (see next section). Capital costs include installed equipment, miscellaneous structures, piping, electrical, instrumentation, site preparation, and engineering and construction costs. Specific to chemical phosphorus removal are pumps and chemical feed systems, a chemical storage tank, a chemical treatment building, and any additional sludge handling and storage equipment.

Operation and Maintenance (O&M) Costs

The O&M costs include the costs for chemicals, power, labor, and chemical sludge disposal. Chemical costs include chemicals required for chemical precipitation. Liquid alum costs range from \$.06 to \$.20 per pound of liquid, while ferric chloride costs range from \$.14 to \$.21 per pound of liquid as of the spring of 2005. Alum is safer and easier to handle and less corrosive than ferric chloride. Generally, the O&M costs for chemical removal systems are greater than EBPR due to chemical addition costs. These costs can be minimized by source reduction practices to minimize phosphorus influent levels to the

wastewater treatment plant.

Combined Enhanced Biological Phosphorus Removal with Chemical Addition

When chemical addition is used in combination with EBPR, it is generally used as a polishing step, usually in secondary treatment. This approach is preferred when EBPR can provide substantial phosphorus removal, but not enough to meet a required effluent phosphorus concentration limit of 1 mg/L based on a monthly average.

General Conclusions

- Two-point chemical addition at the primary and secondary clarifiers is the most cost-effective solution for treatment systems requiring chemical treatment only.
- Consider the nutrient requirements of the activated sludge process, when adding chemicals to the primary clarifiers.
- As part of the design of the phosphorous treatment system, evaluate the capacity of the sludge processing and handling operations.
- Assess the impact of sludge processing residuals and other plant returns on phosphorus loads when evaluating phosphorus removal systems.
- Cut costs for chemicals and treatment by reducing the amount of phosphorous entering the wastewater treatment plant.

Enhanced Biological Phosphorus Removal (EBPR)

Process Description

Conventional activated sludge microorganisms (mixed liquor suspended solids, or MLSS) contain 1.5 to 2.0 percent phosphorus (dry weight measure). Standard engineering estimates expect conventional activated sludge processes to have a removal efficiency of approximately 20 percent. A survey of 59 Minnesota activated sludge wastewater treatment facilities for 2005 found an average phosphorus removal efficiency of 47 percent.

Enhanced biological phosphorus removal (EBPR) processes (see Figure 2) are designed to culture communities of microorganisms in MLSS that have the

ability to store intracellular phosphorus ranging from 5 percent to 30 percent on a dry-weight basis. Subsequent removal of waste activated sludge can produce phosphorus removal efficiencies in the 80- to 90-percent range. Although there is some dispute as to the precise bacterial composition of these communities of microorganisms, they are generally known as phosphorus accumulating organisms (PAOs). These are likely to comprise a variety of bacterial subpopulations including *Acinetobacter*, *Rhodocyclus* and some morphologically identified coccus-shaped bacteria with a diameter of about 1.2 μm .

The EBPR process (see Figure 2) works by providing an anaerobic zone with an ample supply of readily biodegradable carbonaceous oxygen demand (rbCOD). Organic matter in the anaerobic zone is fermented to create a source of volatile fatty acids (VFAs), particularly acetate and propionate, which in turn serve as food sources for PAOs.

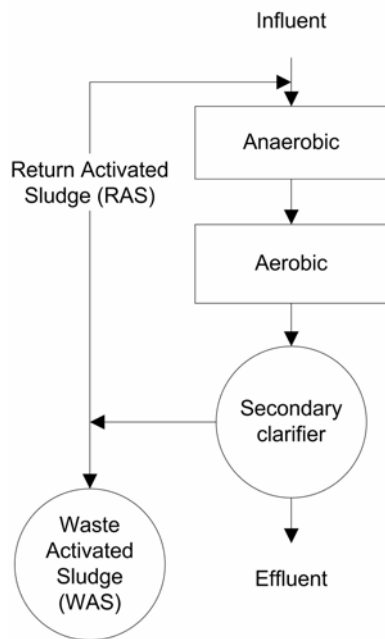


Figure 2. Anaerobic/Aerobic EBPR Process

PAOs are aerobic bacteria and although they cannot reproduce in an anaerobic environment, they do have the unusual ability to consume VFAs under strict anaerobic conditions and, as a result, store intracellular carbon compounds. They obtain energy for this process by metabolizing stored polyphosphate reserves and thereby release phosphorus during this phase at a rate of 0.4 to 0.5 milligrams of phosphorus for every milligram of acetate consumed. The result is a net increase in the amount of

dissolved phosphate across the anaerobic phase of the process. It is helpful to think of the anaerobic phase of an EBPR process as a conditioning tank where PAOs are being prepared for their work in the subsequent aerobic phase.

In the aerobic phase of the process, PAOs are able to multiply and take up phosphate to replenish the supplies depleted in the anaerobic phase. By oxidizing the carbon reserves built up in the anaerobic phase, PAOs are able to store more phosphate under aerobic conditions than was released under anaerobic conditions because considerably more energy is produced by aerobic oxidation of the stored carbon compounds than was used to store them under anaerobic conditions.

Waste activated sludge (WAS) is removed from the system in the secondary clarification processes and transferred to solids handling units. PAO and phosphorus-rich return activated sludge (RAS) is recycled to the anaerobic zone to build up the population of PAOs in the system and to be reconditioned for another EBPR cycle.

Critical Factors for the Success of EBPR

Influent Characteristics

The presence of an adequate source of VFAs is critical to properly condition PAOs in the anaerobic phase of the EBPR cycle. VFAs are produced through the fermentation of rbCOD in the anaerobic zone or can be supplemented from other sources. As a rule of thumb, a minimum influent BOD:P ratio of 25:1 is necessary in order to provide adequate conditions for PAOs to thrive. Note that this ratio is applicable to the influent of the anaerobic phase of the EBPR process. Upstream treatment processes such as primary clarification may remove too much rbBOD for successful PAO conditioning. A more comfortable margin is provided with influent BOD:P ratios of 30:1 to 40:1. Dilute influent characteristics with low BOD concentrations, excessive BOD removal in primary treatment processes and excessive influent or solids dewatering side-stream phosphorus concentrations can cause influent BOD:P ratios to fall below the optimal range for successful EBPR.

Integrity of the Anaerobic Zone

Establishing and maintaining strict anaerobic conditions in the anaerobic zone is critical for PAOs to be able to consume VFAs and store carbon compounds. The presence of oxygen or nitrates (from which O_2 can be

derived) will disrupt the process by placing PAOs at a competitive disadvantage with other bacterial populations. If PAOs fail to accumulate carbon compounds in the anaerobic phase through the metabolism (and release) of stored polyphosphate sources, they will not take up phosphates in the subsequent aerobic phase.

RAS in nitrifying systems designed to remove ammonia will contain significant nitrate concentrations that are not compatible with two stage (aerobic/anaerobic) EBPR systems. In these cases provisions must be made to denitrify the return solids to avoid compromising the integrity of the anaerobic zone. Various de-nitrification EBPR configurations are effective for these conditions, most often including one or more anoxic phases (see Figure 3) where bacterial respiration is dependent on oxygen derived from nitrites or nitrates rather than dissolved oxygen.

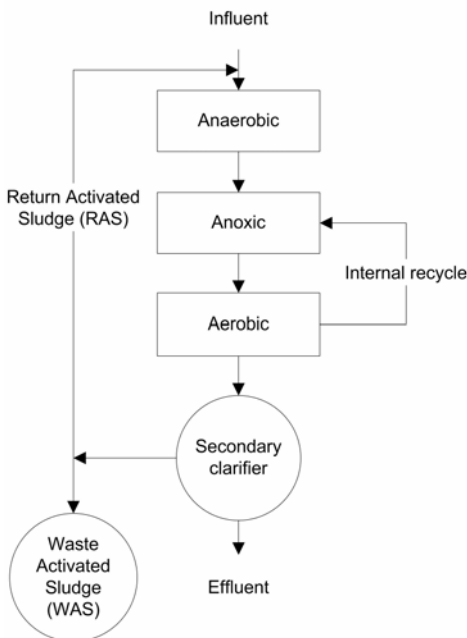


Figure 3. Anaerobic/Anoxic/Aerobic Process

Variability

Flow and load variability should be minimized to optimize conditions for EBPR. Variability in flows can result in variable anaerobic and aerobic contact times which can disrupt the process. Flow and load variability can also impact the influent BOD:P ratio and therefore the availability of sufficient VFAs which can compromise the successful operation of the EBPR systems.

Potential Effluent Quality

Effluent wastewater phosphorus concentrations can be divided into two components:

1. Soluble phosphorus: the fraction that is available for biological uptake in an EBPR system.
2. Particulate phosphorus: the fraction that is subject to settling and flocculation.

An efficient EBPR system followed by good final clarification can achieve effluent phosphorus concentrations of 0.7 mg/L if sufficient VFAs are available in the process. Lower effluent concentrations down to 0.1 mg/L can be achieved through supplemental chemical treatment and advanced effluent filtration techniques.

Operational Considerations

- Dissolved Oxygen: Avoid over aeration. Maintain 0.5 to 1.0 mg/L DO concentrations at the end of the aeration zone. This will allow for the activated sludge process to perform adequately and ensure that excessive dissolved oxygen concentrations are not recycled back to the anaerobic phase.
- Filamentous Control: Avoid over chlorination. Excessive RAS chlorination can harm the EBPR process. The St. Cloud WWTF has reported that more frequent, but less intense, RAS chlorination successfully controls the growth of filamentous bacteria while minimizing adverse impacts on the biological treatment system. Address root causes such as low dissolved oxygen, low food to mass ratio, solids retention time, etc.). Anaerobic and anoxic selector zones should help control filamentous bacteria by placing them at a competitive disadvantage with respect to other types of bacteria.
- Influent BOD:P Ratios: A minimum 25:1 ratio of influent BOD to phosphorus has been reported to be critical for successful EBPR. Source reduction of phosphorus loads can help decrease influent phosphorus loads and improve EBPR efficiency.
- Recycled P Loads: Evaluate phosphorus concentrations and loads returned to the treatment process from solids dewatering operations. Sludge dewatering return flows can contain significant amount of phosphorus that can effectively increase the influent load to the WWTP and reduce the influent BOD:P ratio sufficiently to overwhelm the EBPR

process if insufficient VFAs are available in the anaerobic phase. Equalize return flows rather than batching them. Schedule decant- and sludge-conditioning operations. Treat side-stream flows with chemical precipitants if necessary.

- Secondary Phosphorus Release: This phenomenon occurs in the anaerobic tank if PAOs release stored phosphates but fail to take up available VFAs. This is a problem because subsequent uptake of phosphorus in the aerobic phase will not occur. Causes associated with these conditions include excessive detention times in anaerobic, anoxic or aerobic phases, PAOs settling in primary clarifiers, septic conditions in secondary clarifiers, anaerobic digestion of primary and EBPR sludges, blending of primary and EBPR sludges and failure to aerate stored EBPR sludges.

Capital Costs

The cost of installing or retrofitting the equipment for EBPR is generally thought to be greater than that for chemical phosphorus removal. Capital costs include installation of tanks, or retrofitting existing tanks with baffles if sufficient excess capacity is available, as well as installation of mixing and recycle pumping equipment. Air handling equipment needs to be able to regulate flow to individual treatment zones, so existing blowers and headers may need to be upgraded or modified.

Operation and Maintenance (O&M) Costs

The long term O&M of EBPR systems is generally cost effective compared to chemical phosphorus removal systems. Cost savings result primarily from the reduced chemical and sludge handling costs. Due to their enhanced solids settlability characteristics, EBPR activated sludge systems can handle greater MLSS concentrations than conventional activated sludge processes and therefore have greater organic treatment capacity than similarly sized conventional treatment facilities. Sludge production is significantly less than for chemical phosphorus removal processes, resulting in reduced sludge processing, storage and handling costs.

EBPR's increased O&M costs with respect to conventional activated sludge processes result from the need for additional mixing and pumping requirements. Chemical addition may be required if influent wastewater contains insufficient alkalinity or needs to be supplemented with a source of VFAs. VFA can also be produced through onsite fermentation of primary sludges. Chemical addition may be necessary for effluent

polishing, as a back-up in the event of operational difficulties, or if very low effluent phosphorus concentrations are required.

Sources:

- Jeon, C.O., D.S. Lee and J.M. Park. 2000. Morphological Characteristics of Microbial Sludge Performing Enhanced Biological Phosphorus Removal in a Sequencing Batch Reactor Fed With Glucose As Sole Carbon Source. *Water Science and Technology*. 41(12): 79–84. www.postech.ac.kr/ce/great/publication/interconfer/interconfer11.pdf
- Jeyanayagam, Sam, 2005. The True Confessions of the Biological Nutrient Removal Process, *Florida Water Resources Journal*. Jan. 2005. pp. 37–46. www.fwrj.com/TechArticle05/0105%20tech2.pdf
- Stensel, H. David, 2005. Wastewater Phosphorus Control and Reduction Initiative, April 2005. Prepared for the Minnesota Environmental Science and Economic Review Board. www.meserb.org/phosphorus.htm
- Zilles, Julie L. et al. 2002. Involvement of Rhodocyclus-Related Organisms in Phosphorus Removal in Full-Scale Wastewater Treatment Plants. *Applied Environmental Microbiology*. 68(6): 2763–2769. www.pubmedcentral.nih.gov/articlerender.fcgi?artid=123978

More Information

If you have further questions about the chemical removal process, call David Kortan, 651-296-6010

For more information about the biological removal process information, call Brian Fitzpatrick, 218-828-6071.

You can reach the MPCA toll-free, by calling 800-657-3864. More information is also available at the MPCA Web site: www.pca.state.mn.us