# What every operator should know about biological phosphorus removal

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Biological phosphorus removal (BPR) was first used at a few water resource recovery facilities in the late 1960s. By the 1970s, many engineers developed specific versions of the processes – University of Cape Town; anaerobic/anoxic/oxic; and Modified Ludzack–Ettinger – to remove phosphorus from wastewater. BPR can be a lower-cost alternative to chemical phosphorus removal. As environmental concerns over excess nutrients in receiving streams grew, regulatory agencies in the late 1980s began to require effluent phosphorus limits. Many facilities have made upgrades that included BPR.

| Knowledge | Principle | Practical considerations |
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| Biological phosphorus removal (BPR) | Phosphorus-accumulating organisms (PAOs) can absorb dissolved phosphorus from wastewater and store it in granules within their cells, doubling the phosphorus content of the solids. | BPR is dependent on maintaining a sufficient population of PAOs.<br><br>Overall phosphorus removal occurs as the PAOs are wasted from the system. |
| PAO characteristics | PAOs are aerobic and are similar to other activated-sludge bacteria.<br><br>In an anaerobic environment, PAOs have the ability to sequester readily biodegradable biochemical oxygen demand (BOD). Most other activated sludge bacteria do not. | PAOs require the same environment as found in conventional activated sludge in terms of dissolved oxygen (DO), pH, etc.<br><br>An anaerobic tank is needed prior to the aeration tank to give PAOs an advantage in absorbing BOD. |
| BPR process | For BPR, a facility must have wastewater and return activated sludge (RAS) flowing into an anaerobic tank, then an aerobic tank (typically an aeration basin).<br><br>Anoxic zones and appropriate recycle streams often are used for BPR, as well as for nitrate reduction. | Conventional activated sludge facilities usually can be modified for BPR by adding an anaerobic tank prior to the existing aeration basin.<br><br>Anaerobic basins are smaller, often only 5% to 20% the size of the aeration basin. |
| Anaerobic phosphorus release | The anaerobic uptake of BOD by PAOs requires energy. Since there is no DO, energy cannot be provided by the normal metabolic process. Instead, the PAOs can obtain energy by cleaving a phosphate ($PO_4$) molecule from the internal polyphosphate granule. This phosphate molecule then passes through the cell membrane into the mixed liquor suspended solids (MLSS). | In the anaerobic zone, there is a decrease in BOD and an increase in phosphorus. For BPR, a release of 5 to 50 mg/L is expected. Only soluble BOD will decrease through the anaerobic zone.<br><br>The plant influent phosphorus concentration should not be used to determine release, since it will be affected by the recycle streams and RAS. Collect samples from the beginning and end of the anaerobic basin to determine release.<br><br>Zero or low release can be due to insufficient BOD or low PAO population.<br><br>Phosphorus release problems can be investigated in the lab using a settleometer and adding acetic acid as a food source. |

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| Aerobic luxury uptake of phosphorus | During the aerobic cycle, PAOs absorb phosphate ions from the bulk MLSS and transport them into the cell. Each phosphate ion is added to polyphosphate granules scattered through the cell.<br><br>Creating the granules requires energy, which is provided by metabolism of the BOD absorbed in the anaerobic zone. | Soluble phosphorus will decrease through the length of the aeration basin.<br><br>If DO is low in the aeration basin, uptake of phosphorus may be incomplete.<br><br>Insufficient BOD in the feed to the anaerobic basin also may result in low phosphorus uptake.<br><br>Specific laboratory staining techniques can highlight the phosphorus granules. |
| Phosphorus chemistry | Phosphorus almost always is bound to oxygen as phosphate. It can be found as a single ion with a –3 charge, commonly called "orthophosphate." Phosphate ions can form a chain called "polyphosphate." Phosphate also may be bound to an organic molecule as organic phosphorus. | Untreated wastewater contains phosphorus in many forms.<br><br>Anaerobic and aerobic processes tend to convert most phosphorus to phosphate.<br><br>PAOs can only take up phosphate.<br><br>Polyphosphate and organic phosphorus must be broken down to the orthophosphate form for BPR. |
| Phosphorus element | Unlike BOD, phosphorus cannot be destroyed. Phosphate is soluble. | If phosphorus is not taken up by the PAOs, it will remain in solution and be discharged in effluent.<br><br>It is relatively easy to calculate a mass balance of total phosphorus through a facility. |
| Phosphorus measurements | Because of the many forms of phosphate, care must be used when performing lab analyses.<br><br>Total phosphorus analyses measure every atom of phosphorus, whether in the liquid or solid fraction.<br><br>Reactive phosphorus generally measures all orthophosphate, as well as some simple organic and polyphosphate. Samples can be filtered or allowed to settle so that aliquots for soluble fractions can be analyzed.<br><br>Phosphorus commonly is reported as mg/L P. Some instruments can display results as either mg/L P or mg/L phosphate. Verify the procedures and display settings to prevent confusion. | Most contract labs should be able to perform phosphorus analyses on liquids and solids.<br><br>Total phosphorus analysis requires strong oxidizers and digestion at an elevated temperature.<br><br>Reactive phosphorus testing can be performed quickly using prepared reagent packets or tubes. The resulting blue color is measured in a colorimeter or spectrometer to determine phosphorus concentration. Read the procedures carefully to ensure that proper sample sizes and dilutions are used for the particular packet or tube. Verify that the proper container size is being used in the colorimeter and that the wavelength setting is correct.<br><br>For operational purposes, samples can be collected from the settleometer or other supernatant rather than filtering, but this must be done soon after collecting the sample. |

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| Phosphorus removal drivers | Assuming that there are sufficient PAOs, a specific amount of BOD is needed for the net uptake of a specific amount of phosphorus loading.<br><br>This is commonly expressed as the BOD to phosphorus ratio (BOD:P) of the feed to the anaerobic zone. | Influent BOD is an acceptable measurement, since recycle streams generally are low in BOD.<br><br>Include recycle streams in phosphorus sampling or mathematically to determine total phosphorus to the anaerobic reactor.<br><br>A BOD:P value of less than 20 is unlikely to allow BPR. Ratios greater than 40 should produce good BPR. However, remember that all BOD is not equal for BPR. These ratios are useful for typical municipal wastewater. For treatment of significant industrial contributions, more-detailed BOD analyses should be performed. |
| BOD type | PAOs can only absorb simple organic molecules, known as "volatile fatty acids" (VFAs), under anaerobic conditions. The BOD test does not differentiate organic molecules. Readily biodegradable BOD is a precursor for VFAs. | A soluble BOD or flocced and filtered chemical oxygen demand test is a better measure of food for PAOs. A ratio of either of these to total BOD can be established but may fluctuate seasonally. |
| Collection system effects | Under anaerobic and septic conditions, organic material generally will break down to simpler molecules, increasing the amount that could be used by PAOs. Long, slow, and septic collection systems will help BPR. | Rainy periods causing influx and infiltration may lead to a decrease in BPR performance.<br><br>Seasonal changes in BPR performance may be due to changes in the collection system environment, rather than temperature changes in the basins. |
| Nitrate poisoning | PAOs grow best when there is no other competition for BOD in the anaerobic zone. When RAS containing nitrates enters the anaerobic zone, it creates anoxic conditions. Denitrifying bacteria can then grow, which compete with the PAOs for the BOD. | Measure RAS nitrate weekly and adjust the process to encourage denitrification.<br><br>RAS nitrate levels less than 5 mg/L should be acceptable. Results greater than 10 mg/L may lead to PAO competition. |
| Non-PAO phosphorus removal | Phosphorus is an essential element for all living cells. All bacteria will consume some phosphorus for cell maintenance and growth. | Even when no PAOs are present, there will be a net reduction of phosphorus through the aeration basin. Non-PAO solids will have a phosphorus concentration of about 2% (by weight). |
| Undesirable phosphorus release | Phosphorus can be released from the solids back into the liquid either as bulk granules from the supernatant and decanter liquor from waste activated sludge thickening and dewatering or slowly as the PAOs release stored phosphorus for energy.<br><br>For example, as PAO cells in septic waste activated sludge at the bottom of a gravity thickener die and lyse (break apart), the polyphosphate granules also decompose and become part of the bulk liquid. | Soluble phosphorus will be 0.5 mg/L or less at the end of the aeration basin when BPR is working well.<br><br>Increased effluent phosphorus might be due to release in secondary clarifiers with deep blankets or sludge removal problems.<br><br>Digestion processes increase soluble phosphorus, which can be returned to the process through supernating or decanting.<br><br>Dewatering processes following digestion also may generate high phosphorus recycle streams. |
| Other anaerobic considerations | Anaerobic activity produces desirable BOD. This occurs in the anaerobic zone, but the solids retention time (SRT) typically is short.<br><br>Fermentation is an anaerobic process that can be performed using primary sludge. Biodegradable BOD produced in the sludge blanket or in a thickener is elutriated back to the headworks. | Anaerobic SRT typically is less than 0.5 days. Hydraulic retention time typically is less than 2 hours.<br><br>Fermentation occurs in primary clarifiers or primary sludge thickeners. Anaerobic digesters do not work well as fermenters, because the biodegradable BOD is consumed by the methanogens in the digester. |
| Effluent particulate phosphorus | Effluent total suspended solids generally are biomass that escaped the secondary clarifier. The phosphorus in the biomass will contribute to effluent total phosphorus but can be removed through a filtration process. | If effluent total suspended solids were 10 mg/L, the contribution to effluent total phosphorus would be about 0.6 mg/L. |

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