

## **BIOLOGICAL PHOSPHORUS REMOVAL GUIDE FOR WASTEWATER OPERATORS**

THE WATER PLANET COMPANY  
*www.CleanWaterOps.com*

### **FORMS OF PHOSPHORUS OF INTEREST TO WASTEWATER OPERATORS**

Regulators are typically concerned with two kinds of phosphorus in wastewater: ortho-P and total-P.

Ortho-P (also known as orthophosphate, phosphate, and reactive phosphorus) is soluble. It is the phosphorus that exists in the clear water fraction of a settleometer.

Total-P (also known as total-phosphorus, total phosphate, and TP) is the sum of soluble phosphorus (ortho-P) and the phosphorus that will not pass through a membrane filter.

Phosphorus removal requires the conversion of soluble phosphorus to a particulate and effective TSS removal.

### **MEASURING PHOSPHORUS**

As a way to confuse the working man we suspect, scientists measure phosphorus two ways: “as P” and “as PO<sub>4</sub>-P” (or sometimes expressed “as PO<sub>4</sub>,” which is no different from “as PO<sub>4</sub>-P”). Commercial laboratories report wastewater concentrations as P whereas field testing instruments are often programmed to report results as PO<sub>4</sub>-P. Fortunately, it is easy to convert. In most cases, the default programming can be changed to report as P. But, if not, or if it necessary to review as PO<sub>4</sub>-P data, it can readily be converted to as P by dividing by three. Example: a 21 mg/L as PO<sub>4</sub>-P is the same as 7 mg/L as P.

### **REMOVING PHOSPHORUS FROM WASTEWATER**

In addition to the small amount of phosphorus that is removed at the same time as BOD is removed and bacteria are grown, phosphorus is removed as follows. Chemically using an iron or aluminum product such as ferric chloride, ferrous sulfate, alum, sodium aluminate, or PAC (poly-aluminum chloride). Or, biologically. Or, both.

Whether removed chemically, biologically, or both, phosphorus is removed from wastewater by making it insoluble and removing TSS and the phosphorus that is attached to the TSS.

Operators are encouraged to optimize biological phosphorus removal before using chemicals because – when it can be done – biological phosphorus removal is less costly (actually, often results in operational savings!), creates less sludge, and is more environmentally friendly. This guide discusses biological phosphorus removal only. Operators who cannot meet existing limits using biological removal are encouraged to visit the Wastewater Science page of The Water Planet Company’s website for information on chemical phosphorus removal.

## **BIOLOGICAL PHOSPHORUS REMOVAL: OVERVIEW**

Three things need to happen for biological phosphorus removal to occur. Operators need to cook hamburgers, feed them to the bacteria that “eat” phosphorus, and give them a LOT of air for dessert. Okay, not exactly, but something similar...

First, it is necessary to create volatile fatty acids (VFAs). This happens in septic conditions such as septic tanks, force mains, wet wells, sludge holding tanks, and gravity thickeners. But, not in anaerobic digesters because the digesters break down the VFAs – the acids in the acid/alkalinity ratio – to methane gas.

Second, also in fermentive (anaerobic) conditions, so-called PAOs (phosphate accumulating organisms) need to consume VFAs. As they do, they will temporarily release phosphorus into solution so that the ortho-P concentration in the fermenter effluent is some three times what it was in the influent.

Third, as the PAOs (we like the phrase bio-P bugs) flow into strongly aerobic conditions, they will concentrate phosphorus in their cells such that the phosphorus is pulled out of solution and the mixed liquor becomes as much as 5% phosphorus. (Bacteria are typically around 1% phosphorus.)

When optimized, bio-P (biological phosphorus removal) will reduce the soluble, ortho-P concentration to very, very low concentrations – sometimes well below 0.05 mg/L. The phosphorus, meanwhile, is concentrated in the PAO bacteria, resulting in an effluent TSS that contains 0.05 mg/L of phosphorus for each 1 mg/L of TSS. Meaning, by finding a way to optimize biological phosphorus removal, A plant that produces single digit effluent can – provided an effective way of biologically converting soluble phosphorus to TSS is implemented – produce an effluent with something on the order of 0.5 mg/L total-P.

## **BIOLOGICAL PHOSPHORUS REMOVAL: MORE DETAILED INFORMATION**

An operator who wants to optimize phosphorus removal needs to: (1) optimize the conversion of soluble phosphorus to TSS by creating the best possible habitats for PAOs and (2) optimize TSS removal, something at which most operators are experts. In this guide, we’ll focus on the first item: creating ideal habitats to optimize the conversion of soluble phosphorus to TSS.

The environmental conditions which provide enhanced biological phosphorus removal are: first, a period of zero oxygen followed by, second, highly aerobic treatment.

**Fermentation:** the first step to bio-P.

Two things need to occur in a zero-oxygen environment for effective biological phosphorus removal: (1) VFAs need to be produced and (2) PAOs need to “consume” the VFAs. Volatile acids are easy to make. As mentioned above, volatile fatty acids interfere with effective anaerobic digester operations; VFAs are the “acids” in the acid/alkalinity ratio that is used as a process control tool for anaerobic digesters. In the case of bio-P, we want to put the acids to beneficial use and not destroy them.

For bio-P bugs (aka PAOs, phosphate accumulating organisms) to remove phosphorus, they must first take in VFAs. This has to occur in a zero oxygen environment, but not necessarily the same place that VFAs are formed. The wastewater needs to contain approximately 25 times as much BOD as phosphorus in order to support biological phosphorus removal. As PAOs “eat” VFAs under anaerobic conditions, the bio-P bugs temporarily release a lot of the phosphorus stored within their cells into the wastestream, causing a tripling of the ortho-P concentration.

The fermentation zone (or zones!) can be created in the wastewater mainstream or – provided PAOs are included in the flow – in a sidestream. The key is maintaining sufficiently anaerobic conditions – we’ve found that an ORP of -150 mV or more negative is typically required. The strength of the anaerobic conditions is more important than hydraulic retention time.

Often, the simplest way of realizing bio-P in a wastewater treatment plant not designed to biological phosphorus is to recycle ten percent of the wasted sludge to aeration. As long as the sludge is held in an unaerated tank long enough to ferment, it should both produce VFAs and the PAOs that are contained in the mixed liquor should have an opportunity to anaerobically consume VFAs. Needless to say, if a portion of the waste activated sludge is returned, it will be necessary to increase the wasting rate. Otherwise the mixed liquor concentration will increase.

**Aeration:** the second step to bio-P.

After consuming VFAs, the individual bacteria that “eat” the VFAs must flow into a tank with surplus dissolved oxygen (as high as 2 mg/L) so that they can use the energy they picked up by “eating” the VFAs to multiply and as they do to pull ortho-P out of solution. Under highly aerobic conditions and a pH of 7.0 or higher, the PAOs will take in large amounts of phosphorus, tripling (or more) the amount of phosphorus in their cells. Phosphorus is removed with the bacteria as waste sludge.

We’ve worked with a number of treatment plants that have optimized fermentation but struggled with phosphorus uptake during aeration. Our experience – not reported elsewhere in the literature – is this: underloaded wastewater treatment plants remove so much of the BOD in the pre-aeration tanks that there isn’t enough BOD remaining in the wastewater to promote PAO growth during aeration. And, as a result, the PAOs don’t pull phosphorus out of solution. This is particularly evident in warm wastewater in southern climates.

Notes:

The information contained in this guide is a result of Water Planet’s experience. We’ve worked with operators to optimize phosphorus removal many dozens of wastewater treatment plants.

To make the guide readable, we generalized. For most every number, for most every recommendation, there is an exception. Operators are advised to keep this in mind. Please call or email us with questions or comments.

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