



# Wisconsin Department of Natural Resources Wastewater Operator Certification

## Introduction to Phosphorus Removal Study Guide

January 2009 Edition



### Subclass I

Wisconsin Department of Natural Resources  
Bureau of Science Services  
Operator Certification Program  
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## Preface

This operator's study guide represents the results of an ambitious program. Operators of wastewater facilities, regulators, educators and wastewater businesses, jointly prepared the objectives and exam questions for this subclass.

How to use this study guide with references

In preparation for the exams you should:

1. Read all of the key knowledges for each objective.
2. Use the resources listed at the end of the study guide for additional information.
3. Review all key knowledges until you fully understand them and know them by memory.

It is advisable that the operator take classroom or online training in this process before attempting the certification exam.

Choosing A Test Date

Before you choose a test date, consider the training opportunities available in your area. A listing of training opportunities and exam dates is available on the internet at <http://dnr.wi.gov>, keyword search "operator certification". It can also be found in the annual DNR "Certified Operator" or by contacting your DNR regional operator certification coordinator.

## Acknowledgements

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## **Part 1 - Biological Removal**

### **Chapter 1 - Theory and Principles**

#### **Section 1.1 - Definitions**

- 1.1.1 Define aerobic (oxic) [O<sub>2</sub>].  
A condition in which free and dissolved oxygen is available in an aqueous environment.
- 1.1.2 Define Anoxic [NO<sub>2</sub>, NO<sub>3</sub>, SO<sub>4</sub>].  
A condition in which oxygen is only available in a combined form such as nitrate (NO<sub>3</sub>), nitrite (NO<sub>2</sub>) or sulfate (SO<sub>4</sub>) in an aqueous environment.
- 1.1.3 Define Anaerobic [Ø].  
A condition in which free, dissolved, and combined oxygen is unavailable in an aqueous environment.
- 1.1.4 Define Phosphate-Accumulating Organisms (PAOs).  
Microorganisms (bacteria) that uptake and store orthophosphate in excess of their biological requirements.
- 1.1.5 Define Volatile Fatty Acids (VFAs).  
When organic material undergoes fermentation reactions, smaller and more readily available organic molecules are formed known as volatile fatty acids (VFAs). VFAs typically found in wastewater are acetic acid (acetate) and propionic acid. VFAs provide the food for PAOs.
- 1.1.6 Define Polyhydroxyalkanoates (PHA).  
Polyhydroxyalkanoates (PHAs) are energy-rich carbon polymers inside a bacterial cell, which are converted from readily available organic molecules such as volatile fatty acids (VFAs) in the wastewater. PHAs are the intracellular energy storage of the phosphorus accumulating organisms (PAOs). The PAOs utilize PHA as a energy source to uptake phosphorus from the wastewater in the aerobic zone of the biological phosphorus removal process.
- 1.1.7 Define Sludge Age.  
Sludge age is the length of time a particle of activated sludge stays in the treatment plant measured in days. In a biological phosphorus removal plant, sludge age is the amount (lbs) of mixed liquor suspended solids in all the biological reactors divided by the suspended solids withdrawn from the system per day (lbs per day of waste activated sludge).
- 1.1.8 Define Selector Hydraulic Retention Time (HRT).  
The given time it takes wastewater, including any return flows, to pass through a tank (selector).
- 1.1.9 Define Polyphosphate (Poly-P).  
Polyphosphate is a string of phosphate (PO<sub>4</sub>) groups joined together. It is present in all

cells but the PAOs are capable of accumulating excess polyphosphate in their cells thereby accomplishing biological phosphorus removal.

1.1.10 Define Selector.

A selector is part of the treatment system that selects for a specific type of microorganism by providing an environment (anaerobic, anoxic, aerobic) that favors its growth.

1.1.11 Define Fermentation.

The process where bacteria degrades organic matter under anaerobic conditions, such as in a collection system, primary clarifier, anaerobic selector, or fermenter tank.

1.1.12 Define Substrate.

The food or chemical on which an organism depends for growth. The organic matter in wastewater (as measured by the BOD5 test) is a substrate for the microorganisms in activated sludge. In biological phosphorus removal systems, volatile fatty acids are a readily available substrate used by phosphorus accumulating organisms (PAOs).

1.1.13 Define Soluble BOD.

Soluble BOD is a sample that has been filtered through a 0.45 µm filter. Soluble BOD includes Volatile Fatty Acids (VFAs) and organic material that will readily ferment to create more VFAs in an anaerobic selector.

## **Section 1.2 - Wastewater Characteristics**

1.2.1 Discuss the importance of the influent BOD or COD and total phosphorus ratio in enhanced biological phosphorus removal.

The success of removing phosphorus biologically depends upon the amount of organic material, expressed as either BOD5 or COD, and total phosphorus, in the influent wastewater entering the anaerobic selector. An adequate amount of organic material must be available to support phosphorus accumulating organisms (PAOs). Studies of operations have shown that a BOD5/P ratio of at least 20:1 or a COD/P ratio of at least 45:1 is needed for biological phosphorus removal.

1.2.2 Discuss the importance of the wastewater volatile fatty acid (VFA) content in enhanced biological phosphorus removal.

The organic material entering an anaerobic selector must be soluble and readily available to phosphorus accumulating organisms (PAOs). The smallest molecules that organic material can be broken into are volatile fatty acids (VFAs) that are then utilized by PAOs to form and store PHAs for later use. It is this VFA use and PHA storage that is the primary mechanism that gives PAOs a selective advantage.

Municipal wastewater that ferments in its travel through a collection system can be a good source of VFAs for EBPR operations. The VFA most easily utilized by PAOs is acetic acid (CH<sub>3</sub>-COOH).

- 1.2.3 Discuss the change in influent wastewater characteristics due to excessive infiltration/inflow (I/I) and the effect on biological phosphorus removal.

I/I can dilute the organic matter in the raw wastewater resulting in an insufficient supply of volatile fatty acids to the PAOs. Higher flow rates associated with I/I can reduce the hydraulic detention time in the anaerobic selector. High flow rates can result in the loss of solids from the clarifiers. This will increase effluent phosphorus because of the phosphorus stored in the biomass. Loss of solids may also result in the “washout” of PAOs from the plant because of their relatively slower growth rate.

### Section 1.3 - Biological Principles

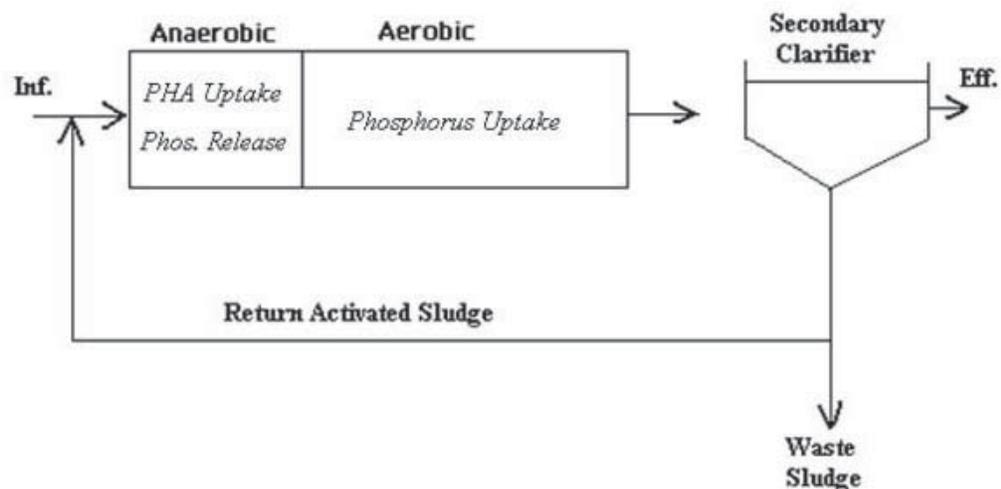
- 1.3.1 Describe the basic theory of Enhanced Biological Phosphorus Removal (EBPR).  
EBPR relies on the selection and proliferation of a microbial population capable of uptaking orthophosphate in greater amounts than their normal biological growth requirements.

Enhanced biological phosphorus removal is a process that uses alternating anaerobic and aerobic zones to provide an environment that encourages the growth of Phosphorus Accumulating Organisms (PAO). PAOs store excess polyphosphate in their cell mass and phosphorus is removed with the waste sludge. See figure 1.3.1.1

Graphic Courtesy of Jeremy Cramer, Stevens Point

Figure 1.3.1.1

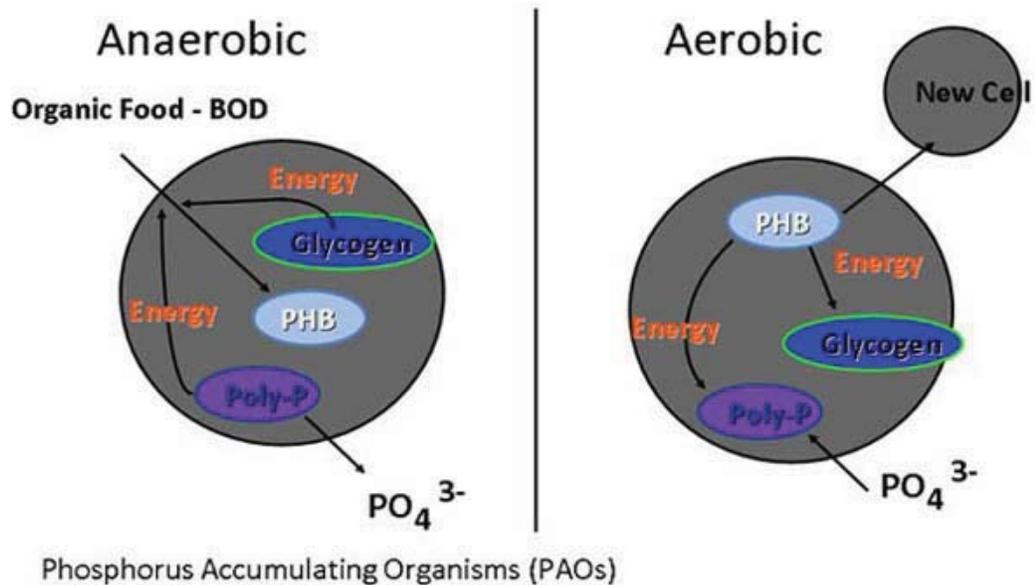
A typical EBPR reactor configuration.



- 1.3.2 Describe and show the mechanism of biological phosphorus removal (EBPR).  
See figure 1.3.2.1 below. The unique feature of EBPR is the anaerobic selector used in the treatment process.

Figure 1.3.2.1

## Mechanism of BPR

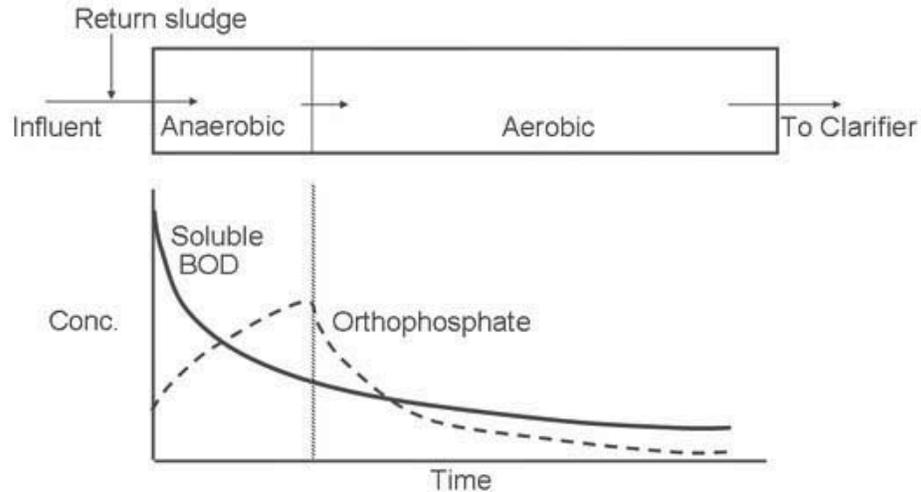


- 1.3.3 Discuss the reactions that occur in the anaerobic zone. See figure 1.3.2.1 above. Phosphorus Accumulating Organisms (PAOs) use poly-phosphate and glycogen stored in their cells as energy sources to enable them to uptake VFA. VFA are converted to Polyhydroxyalkanoates (PHA) and stored in the cells of PAOs. As they take up VFA, the PAOs release orthophosphate into the mixed liquor. PAOs do not grow in the anaerobic zone but their ability to uptake food in the form of VFAs gives them a competitive advantage over other bacteria.
- 1.3.4 Discuss the reactions that occur in the aerobic zone. See figure 1.3.2.1 above. In the aerobic zone PAOs use PHA as a source of carbon and energy for metabolism and cell growth. PAOs will also restore their supplies of glycogen and poly-phosphate in the aerobic zone. To replenish their stored poly-phosphate, PAOs will take up excess phosphate from the mixed liquor which is the mechanism of biological phosphorus removal.
- 1.3.5 Describe and show the phosphorus and BOD profile through a treatment plant. In the anaerobic zone PAOs will rapidly take up BOD (as VFAs) and release orthophosphate into the mixed liquor. As the wastewater passes through the anaerobic zone VFA will rapidly decrease and orthophosphate will increase. In the aerobic zone BOD will continue to decrease. As PAOs restore their poly-phosphate supplies in the aerobic zone the concentration of orthophosphate in the mixed liquor will rapidly decrease. See figure 1.3.5.1 below.

Graphic courtesy of Jenchie Wang, Symbiont

Figure 1.3.5.1

**Profile of BOD and P in mixed liquor as it passes through an EBPR plant**



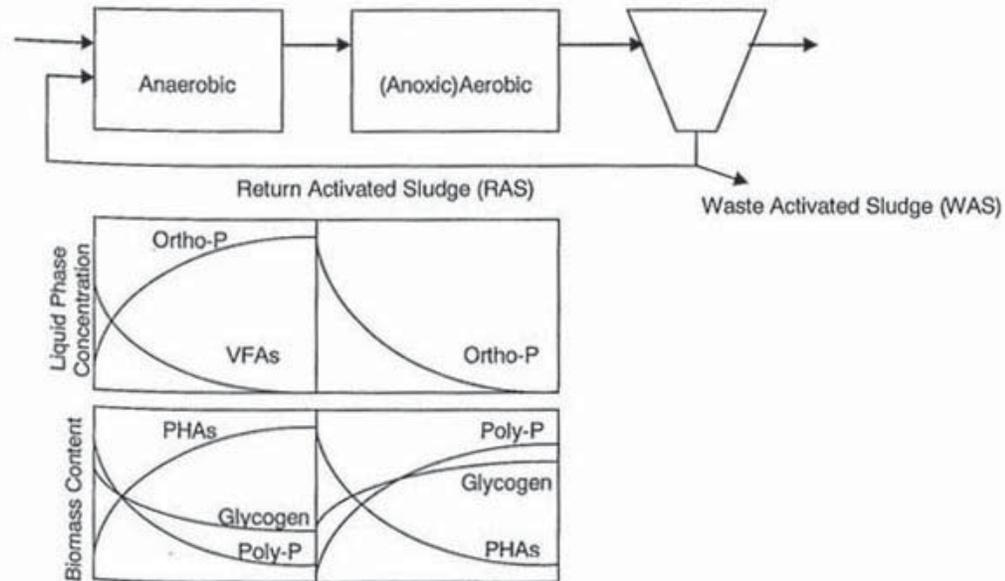
1.3.6 Describe and show the concentration profiles through the plant of glycogen, VFA, PHA, Poly-P, orthophosphate.

Under anaerobic conditions PAOs take up VFA from the mixed liquor and store it as PHA within their cells. To do this PAOs use the glycogen and poly-phosphate as energy sources - depleting their stores of these compounds.

Under aerobic conditions PAOs use up their stored PHA for metabolism and growth and to restock their supplies of glycogen and poly-phosphate. To build up their supply of poly-phosphate PAOs will take up excess orthophosphate from the mixed liquor in the aerobic zone.

See Figure 1.3.6.1 below from WEF MOP 25, 2005. It depicts typical concentration profiles in a generic EBPR system.

Figure 1.3.6.1



1.3.7 Discuss how the anaerobic selector favors PAOs.

Under anaerobic conditions, PAOs are at a competitive advantage to uptake a readily available food source (VFAs) and therefore "selected for" in this environment. Most other bacteria cannot uptake the VFAs under anaerobic conditions.

**Section 1.4 - Performance Limiting Factors**

1.4.1 Discuss the effect of nitrate and dissolved oxygen in the anaerobic zone.

If nitrate or dissolved oxygen are present, uptake of VFAs and phosphorus release will be inhibited.

1.4.2 Describe the possible impact of nitrification on biological phosphorus removal.

Nitrification is the process where ammonia is converted to nitrates. If nitrates are present in the anaerobic zone (Ø) it becomes anoxic (NO<sub>3</sub>). Denitrifying bacteria under anoxic conditions will uptake VFAs, thus decreasing the VFAs available for PAOs.

**Chapter 2 - Operation and Maintenance**

**Section 2.1 - Definitions**

2.1.1 Define struvite.

Struvite is magnesium ammonium phosphate (MgNH<sub>4</sub>PO<sub>4</sub>(H<sub>2</sub>O)<sub>6</sub>). It forms hard, very insoluble, white, yellowish-white, or brownish-white crystals.

2.1.2 Define nitrification.

A biological process where nitrifying bacteria convert nitrogen in the form of ammonia (NH<sub>3</sub>) into nitrite (NO<sub>2</sub><sup>-</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>) under aerobic conditions.

2.1.3 Define denitrification.

A biological process where bacteria convert nitrate ( $\text{NO}_3^-$ ) to nitrogen gas ( $\text{N}_2$ ) under anoxic conditions.

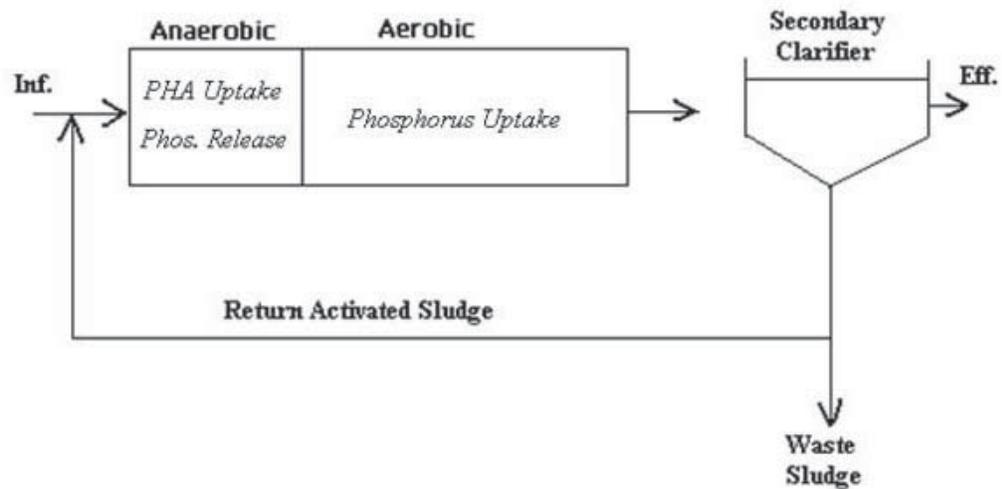
**Section 2.2 - Reactors**

2.2.1 Describe and show typical enhanced biological phosphorus removal (EBPR) reactor configuration.

Graphic courtesy of Jeremy Cramer, Stevens Point.

Figure 2.2.1.1

A typical EBPR reactor configuration.



2.2.2 Discuss why anoxic zones are used along with anaerobic zones as part of biological phosphorus removal.

The recycling of nitrates to the anaerobic selector will interfere with the biological phosphorus removal process just as oxygen would. Anoxic zones are provided to denitrify ( $\text{NO}_2 + \text{NO}_3 \rightarrow \text{N}_2$ ) recycle streams. Where recycle streams, for example return activated sludge (RAS), contain nitrates, anoxic zones can ensure that nitrates are not returned to the anaerobic selector.

2.2.3 Discuss the importance of selector hydraulic residence time.

Hydraulic residence time (HRT) is a very important operational parameter in allowing enough time for EBPR reactions to take place. Hydraulic residence time is the contact time between the incoming influent containing the readily available organic substrate and nutrients with the microorganisms (PAOs). The amount of VFAs in the incoming wastewater will determine the optimum HRT for the anaerobic selector. Higher VFAs in the influent require less HRT. Conversely low VFAs in the influent require a longer HRT. A HRT of 1-3 hours in the anaerobic zone is all that is usually needed for the necessary biochemical reactions to occur for successful EBPR in municipal wastewater treatment plants, provided sufficient VFAs are available. The hydraulic residence time of an anaerobic selector can be

effected by high influent flows caused by infiltration/inflow (I/I) and high return activated sludge (RAS) rates with resultant poor phosphorus removal.

- 2.2.4 Discuss the importance of sludge age in the treatment system on biological phosphorus removal.

As with all activated sludge systems, sludge age determines how long the biomass stays in the biological part of the treatment system. Because biological phosphorus removal is compartmentalized into anaerobic, anoxic, and aerated zones, all biological zones must be taken into consideration when calculating sludge age. Selectors are usually much smaller than that of aeration zones and should be taken into account when determining sludge age.

The proper sludge age ensures the optimization of the biochemical reactions that need to take place and for the biomass to uptake excess phosphates in the aerobic basins (see key knowledge 1.3.5). Too short a sludge age and insufficient treatment can occur with resultant poor effluent quality. As sludge age increases in an activated sludge system, nitrification becomes a factor and the need for anoxic zones becomes critical for denitrification and the removal of nitrates. Long sludge ages such as in extended aeration systems, can lead to secondary release of phosphorus through biomass decay. Long sludge ages can also result in biochemical reaction problems for PAOs. Sludge ages of 5-30 days are likely to be observed in successful EBPR plants.

- 2.2.5 Describe and show the different treatment configurations used for biological phosphorus removal.

There are many types of enhanced biological phosphorus removal systems. Some of the more common types you may hear about are A/O (Anaerobic/Oxic), A<sup>2</sup>/O (Anaerobic/Anoxic/Oxic), Modified Bardenpho, University of Capetown (UCT and Modified UCT) and various oxidation ditch designs. While some are complicated, all employ the basic theory and principles of EBPR design: an anaerobic zone for PAO selection and the release of phosphorus, anoxic zones for nitrate control, and aerobic zones for phosphorus uptake. For additional information about the various configurations used for EBPR, see the references listed at the end of this study guide.

- 2.2.6 Describe how bacterial solids are kept in suspension in selector tanks.

Mixed liquor suspended solids are kept in suspension through the use of various submersible mixers as well as the motion from influent and recycle flows and baffling.

## **Section 2.3 - Methods**

- 2.3.1 List some operational and design parameters that are important in successful biological phosphorus removal.

For wastewater treatment plants utilizing biological phosphorus removal, specific conditions must exist for them to function properly that favors phosphorus accumulating organisms:

1. BOD<sub>5</sub> (or COD) /Total P ratio: As discussed in key knowledge 1.2.1, the influent BOD<sub>5</sub> or COD to total phosphorus ratio is critical for PAOs to grow, function, and take up phosphorus from solution. The influent BOD<sub>5</sub> or COD must be in a form that is readily

available to PAOs, such as volatile fatty acids. A minimum BOD<sub>5</sub>/total P ratio of 20:1 or a COD/total P ratio of 45:1 is needed for successful bio-P removal.

2. Sludge Age (SA) and Hydraulic Retention Time (HRT): The contact time between the influent and the bacteria (HRT) as well as the proper sludge age (SA) for the microbial biochemical reactions to take place in the biomass are critical for PAO growth, metabolism and selection. These parameters are discussed further in key knowledges 2.2.3 and 2.2.4.

3. Temperature: Research shows that effective phosphorus removal has been shown to occur between 5- 30°C as long as proper sludge ages are provided for cold and warm weather temperatures. In fact, PAO's may be at a selective advantage in colder temperatures (5-10°C).

4. Internal Recycle Flows: Internal recycles are used in EBPR systems to create favorable conditions for PAO selection and growth. Common internal recycle flows include return activated sludge (RAS), anoxic zone to anaerobic zone recycles, and aerobic to anoxic zone recycles. In all cases, an operator must pay close attention to avoid returning oxygen or nitrates to anaerobic zones.

## **Section 2.4 - Biosolids Issues**

2.4.1 Describe solids production using biological phosphorus removal.

Generally, there will be fewer solids produced with EBPR than with chemical precipitation. However, depending on its configuration, an EBPR plant may generate more solids than a conventional activated sludge plant with no phosphorus removal.

2.4.2 Describe the effects of phosphorus removal on land applications of biosolids.

The amount of biosolids that can be applied to agricultural land is determined in part by the nutrient needs of the crops grown. Chemical precipitation and EBPR will both increase the phosphorus content of biosolids. This may reduce the amount of biosolids that can be applied per acre of land. Phosphorus in EBPR biosolids may be somewhat more soluble and therefore more available to crops than chemically precipitated phosphorus, which is more tightly bound.

2.4.3 Discuss operational problems caused by the formation of struvite.

Struvite deposits can clog pipes and valves, interfere with instrumentation and reduce the operating life of equipment such as belt filter presses. Struvite commonly forms in anaerobic digesters where ammonia, magnesium, and phosphate are present and pH increases. EBPR plants with anaerobic digesters have a higher potential for struvite formation than conventional activated sludge plants.

## **Chapter 3 - Monitoring, Process Control, and Troubleshooting**

### **Section 3.1 - Definitions**

3.1.1 Define "secondary release".

The release of phosphorus in a EBPR system not associated with substrate (food) uptake.

Secondary release is a release of phosphorus in your plant where you do not want it to happen.

## **Section 3.2 - Sampling & Testing**

3.2.1 List process control lab tests that are used to monitor phosphorus removal.

- Total Phosphorus
- Orthophosphate
- BOD5
- Soluble BOD5
- Nitrates
- COD (Chemical Oxygen Demand)
- VFA (Volatile Fatty Acids)
- Percent Phosphorus content in total suspended solids

3.2.2 Describe Total Phosphorus, its sampling locations, and the reason for sampling.

Total phosphorus is the sum of all orthophosphates and condensed phosphates, soluble and particulate, as well as organic and inorganic fractions using acid digestion. Total phosphorus is then determined by either colorimetric, spectrophotometric, or ion chromatographic methods.

Sampling Locations: Influent, Primary Clarifer, Effluent, Recycle Streams, and Effluent.

Reason for sampling: It is important to know and monitor the amount of phosphorus at these locations in order to make process control changes. Effluent phosphorus results may also be required by your discharge permit. It is important to know what the levels of phosphorus are entering your facility because high influent phosphorus loading could be the cause of high effluent phosphorus levels.

3.2.3 Describe orthophosphate, its sampling locations, and the reason for sampling.

Orthophosphate is the soluble or reactive form of phosphorus. Orthophosphate can be determined without acid digestion using simple test kits that can quickly determine orthophosphate levels using colorimetric measurement. The test kit estimates total phosphorus. Operators can compare total phosphorus results to orthophosphate results and determine a multiplication factor which can be used to determine a total phosphorus value. Orthophosphate will be some fraction of the total phosphorus. It is good to monitor the wastewater flow entering and leaving the anaerobic selector for orthophosphate on a regular basis. The anaerobic zone effluent should be three to four times (3X - 4X) higher than the influent. This tells the operator if a good phosphorus release is taking place in the anaerobic zone.

Sampling Locations: Influent, Primary Clarifier Effluent, Anaerobic zone, Aerobic zone, Recycle streams, Final Clarifiers, and Effluent.

Reason for sampling: Quick and easy way to estimate phosphorus levels. Monitor phosphorus release in the anaerobic selector.

3.2.4 Describe BOD<sub>5</sub>, its sampling locations, and the reason for sampling.

BOD<sub>5</sub> is the measurement of oxygen utilized during a five day incubation period at 20 degrees Celsius. It is used to determine the organic strength of the wastewater. The BOD concentration entering a bio-P facility is important to know along with the influent phosphorus concentration in order to determine a BOD to Total Phosphorus ratio. This ratio should be 20:1 or greater. If this ratio is lower, the facility would be considered BOD-limited and may have trouble achieving good biological phosphorus removal.

Sampling Locations: Influent and Primary Clarifier Effluent.

Reason for sampling: To monitor BOD<sub>5</sub>:TP ratio.

3.2.5 Describe soluble BOD<sub>5</sub>, its sampling locations, and reason for sampling.

Soluble BOD is a BOD<sub>5</sub> test run on a sample that is filtered through a 0.45 µm filter. The soluble fraction of the BOD entering the anaerobic zone is important to know because PAOs are able to gain their competitive advantage in the anaerobic zone by being able to use the soluble fraction of the BOD entering. The success of the bio-P process is dependant on having readily degradable food source or SBOD available to the PAOs.

Sampling Locations: Influent and Primary Effluent.

Reason for sampling: To have information on the amount of food (BOD<sub>5</sub>) that is more readily available to the microorganisms, especially PAOs.

3.2.6 Describe nitrates, its sampling locations, and reason for sampling.

Nitrate-nitrogen is an oxidized form of nitrogen. The nitrates found in wastewater are generated by the nitrification process. Nitrates are measured by using either an ion-specific probe or a colorimetric test. Portable test kits are available to measure nitrates for process control purposes. It is important to know if nitrates are present in the anaerobic zone. This is important because if the bio-P process is to be successful, no nitrates can be present in the anaerobic zone. If you nitrify at your facility, you will need to denitrify before the return activated sludge enters the anaerobic zone. Sidestreams should also be tested for nitrates.

Sampling Locations: Return Activated Sludge, Anaerobic zone, Aerobic zone, and Sidestreams

Reason for sampling: To monitor nitrates entering or in the anaerobic zone.

3.2.7 Describe COD (Chemical Oxygen Demand), its sampling locations, and reason for sampling.

The COD test is a measurement of the amount of organic compounds in a sample. COD has advantages over the BOD test for process control because the results are available in about three hours rather than five days. The COD to P ratio for EBPR should be at least 45:1.

Sampling Locations: Influent, Primary Effluent, and Final Effluent.

Reason for sampling: Monitoring the COD:P ratio.

3.2.8 Describe VFA (Volatile Fatty Acids), its sampling locations, and reason for sampling.

Volatile Fatty Acids provide the food that PAOs uptake in the anaerobic zone. Sufficient VFAs must be present entering the anaerobic zone for successful EBPR. Testing for VFAs in the influent to the anaerobic selector can help determine if VFAs are a performance limiting factor. One reference states that 5 - 10 mg/L of VFAs are needed per mg/L of phosphorus to be removed (MOP-29, pp272). For total volatile fatty acids as acetic acid, Standard Methods 5560C can be used. This method is good for process control - VFA information. Standard Methods 5560 C is a distillation lab procedure that provides VFA analysis for water soluble fatty acids up to six carbon atoms. Calculations and reporting are on the basis of acetic acid, the most easily usable fatty acid by PAOs. Additionally, analysis for the individual volatile fatty acids can be by gas chromatography, but this may be beyond what is needed for process control information.

Sampling Locations: Influent entering an anaerobic zone.

Reason for sampling: To determine whether VFAs are a limiting factor for EBPR.

3.2.9 Describe the percent phosphorus content in total suspended solids, its sampling locations, and reason for sampling.

A sample is filtered through a 0.45  $\mu\text{m}$  membrane and the phosphorus content of the filtered and unfiltered portion is determined. The phosphorus content of the solids is the difference between the filtered and unfiltered samples. The percent phosphorus is then calculated by dividing the phosphorus value by the total suspended solids of the sample and multiplying by 100 to give a percentage.

Sampling Location: Wastewater Activated Sludge (WAS).

Reason for sampling: Phosphorus is removed with the sludge, therefore the percent phosphorus in the sludge indicates the effectiveness of the process. It is also important to know the phosphorus content of sludge for land application programs.

3.2.10 Discuss in-line monitoring of the biological phosphorus process using oxidation reduction potential (ORP) and dissolved oxygen (DO) meters.

While dissolved oxygen is often used to monitor anaerobic, anoxic, and aerobic processes, it is limited in its accuracy in measuring very low levels to zero oxygen in solution, thus true and actual anaerobic or anoxic conditions cannot be measured with a dissolved oxygen meter.

In wastewater, the oxidation-reduction potential is the tendency of the solution to either gain or lose electrons. Oxidizing agents take on electrons while reducing agents give up electrons. Raw wastewater typically contains more reducing agents than oxidizing agents and in the biological treatment of wastewater bacteria, in the presence of oxygen, oxidizes

these reducing agents.

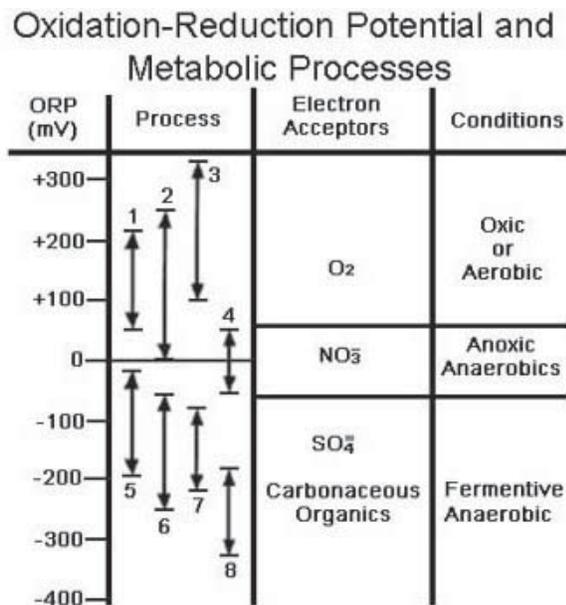
ORP measures the movement of electrons in wastewater solution. It is a measurement of the ratio of oxidizing and reducing agents in solution. ORP is measured in millivolts (mV). It is an excellent and preferred method for measuring anaerobic (a highly reducing environment), anoxic (a reducing environment), and aerobic (an oxidizing environment), all necessary and very important conditions needed in the successful biological removal of phosphorus from wastewater.

The range of ORP readings for such environments can be found in Figure 3.2.10.1 below. Graphic courtesy of Gronsky, et al., 1992.

Key to Figure:

- |                               |                             |
|-------------------------------|-----------------------------|
| 1 - Organic Carbon Oxidation  | 5 - Polyphosphate Breakdown |
| 2 - Polyphosphate Development | 6 - Sulfide Formation       |
| 3 - Nitrification             | 7 - Acid Formation          |
| 4 - Denitrification           | 8 - Methane Formation       |

Figure 3.2.10.1



### Section 3.3 - Data Understanding & Interpretation

3.3.1 Discuss the fate of phosphorus as it passes through a treatment plant.

All of the phosphorus that enters a treatment plant in the influent will leave the plant in either the effluent or settled sludge. When using chemical phosphorus removal, the metal phosphate precipitate settles with the sludge and the phosphorus is removed when sludge is wasted. When using biological phosphorus removal, the phosphorus accumulating organisms (PAOs) settle with the sludge and are removed during sludge wasting. Phosphorus that does not settle with the sludge will be discharged in the effluent. While some of the effluent phosphorus is dissolved (orthophosphate), total suspended solids (TSS) in the effluent also contain phosphorus. Adequate sludge wasting and keeping the effluent TSS low will help keep effluent phosphorus low.

3.3.2 Discuss factors that result in secondary release of phosphorus and its effects.

Secondary phosphorus release can be defined as phosphorus released from a cell which is not associated with intercellular energy storage. In other words, the secondary phosphorus released is not able to be taken up by the phosphorus accumulating organisms (PAOs) which results in a higher phosphorus concentration in the liquid phase, and a reduced phosphorus removal efficiency. The primary causes of secondary phosphorus release are:

1. The retention time of anaerobic selector of Bio-p process is too long.
2. The retention time of settled sludge in the clarifier is too long.
3. The retention time of aerobic stage of a Bio-p process is too long, causing cell lysis and phosphorus release.
4. The long storage of waste sludge causing phosphorus to be released back into solution and then returned back into the plant through sidestreams.

### **Section 3.4 - Corrective Actions**

3.4.1 Discuss a control strategy for nitrates.

If a treatment plant is required to remove ammonia, the plant will be designed to nitrify. Many plants will nitrify, even if ammonia removal is not required, if a longer sludge age is used. Care must be taken not to introduce nitrates into the anaerobic zone with RAS or mixed liquor recycles or side-streams.

If ammonia removal is not required, nitrates may be controlled by maintaining a short sludge age, although this can be difficult. RAS, mixed liquor and side-streams should be managed to limit the nitrates returned to the anaerobic zone.

An anoxic zone is often incorporated in BPR plants to promote denitification.

## **Chapter 4 - Safety**

### **Section 4.1 - Definitions**

4.1.1 Discuss the potential safety hazards when operating a biological phosphorus removal system.

1. Falling in while sampling.
2. Slipping on wet or icy conditions.
3. Biohazards of sewage.
4. Sample preservation and analysis (strong acid).

## **Chapter 5 - Calculations**

### **Section 5.1 - Calculations**

- 5.1.1 Will an influent wastewater to a treatment plant be amenable to biological phosphorus removal if the influent BOD5 is 275 mg/L and the influent phosphorus is 12 mg/L? A ratio of > 20:1 is needed.

GIVEN:

Influent BOD5 = 275 mg/L

Influent P = 12 mg/L

FORMULA & SOLUTION:

Influent BOD5/Phosphorus Ratio =

Influent BOD5(mg/L) ÷ Influent Phosphorus (mg/L)

= 275 mg/L ÷ 12 mg/L

= 23:1 = YES, this ratio indicates it will be amenable to biological phosphorus removal

- 5.1.2 Determine the hydraulic retention time in an anaerobic selector.

GIVEN:

Influent Flow = 1.25 MGD

Selector Volume = 0.050 MG

FORMULA & SOLUTION:

Detention Time (Hrs) =

[Tank Volume (MG) ÷ Influent Flow (MGD)] × 24hrs/day

= [0.050 MG ÷ 1.25MGD] × 24 hrs/day

= 1 hr

- 5.1.3 Determine the sludge age in a biological phosphorus removal plant.

GIVEN:

Total Volume of the Anoxic, Anaerobic and Aeration Basins = 475,000 gallons

Mixed Liquor Suspended Solids = 2200 mg/L

Wasting Rate = 12,000 gallons per day

WAS concentration = 4000 mg/L

FORMULA:

Sludge Age (Days) = Mass of solids in biological reactors (lbs) ÷ Solids Removed Daily (lbs)

= [Total Reactors Volume (MG) × MLSS (mg/L) × 8.34 lbs/MG/mg/L] ÷ [WAS Rate (MGD) × WAS concentration × 8.34 lbs/MG/mg/L]

= (0.475 MG × 2200 mg/L × 8.34 lbs/MG/mg/L) ÷ (0.012 MGD × 4000 mg/L × 8.34 lbs/MG/mg/L)

= 8715 lbs MLSS ÷ 400 lbs WAS

= 22 days

- 5.1.4 Given data, calculate the phosphorus load from the sidestream (decant) from a sludge storage tank.

GIVEN:

Decant Flow = 75,000 gallons = 0.075 MG

Decant Phosphorus Concentration = 35 mg/L

FORMULA/SOLUTION:

Phosphorus Load (lbs) = (Decant Flow in MG) × (Phosphorus Concentration in mg/L) × 8.34  
lbs/MG/mg/L

= 0.075 MG × 35 mg/L × 8.34 lbs/MG/mg/L

= 22 lbs per day

## **Part 2 - Chemical Removal**

### **Chapter 6 - Theory and Principles**

#### **Section 6.1 - Definitions**

6.1.1 Define eutrophication.

The process of excessive growth of plant and algae in receiving waters due to dissolved nutrients and their decomposition.

6.1.2 Define "Chemical Precipitation".

Precipitation is the formation of a solid in a solution during a chemical reaction. Soluble phosphorus can be changed to a solid that will settle and can be removed with the sludge. Several different metal salts are commonly used to chemically precipitate phosphorus.

6.1.3 Define "Metal Salt".

A term used to describe iron, aluminum, and calcium compounds used in chemical phosphorus removal.

6.1.4 Define Coagulation.

The clumping together of very fine particles into larger particles (floc) caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles, allowing them to come closer and form larger clumps. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

6.1.5 Define crystallization.

The formation of solids from solution due to changes in temperature and concentration.

6.1.6 Define flocculation.

The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing. In biological wastewater treatment where coagulation is not used, clumping may be accomplished biologically.

#### **Section 6.2 - Origins & Impacts**

6.2.1 Explain how the discharge of phosphorus may impact receiving waters.

Phosphorus is one of the key nutrients that contribute to eutrophication and excess algae growth in rivers and lakes. The decomposition of excess plant matter may reduce the level of dissolved oxygen in the receiving water which affects aquatic life.

6.2.2 List some major sources of phosphorus in influent wastewater.

- A. Human wastes.
- B. Industrial wastes.
- C. Household wastes.
- D. Cleaners and detergents.

6.2.3 Discuss the potential phosphorus loading from hauled wastes.

Hauled wastes, including septage, holding tank waste, leachate, and commercial and

industrial wastes, can be significant sources of phosphorus. It is good practice to sample each load of hauled wastes. The cost of phosphorus removal should be considered in setting fees for treating hauled wastes.

### **Section 6.3 - Chemicals & Chemical Reactions**

6.3.1 List the most common chemicals (metal salts) used for phosphorus removal.

1. Ferric Chloride
2. Ferrous Chloride
3. Ferrous Sulfate
4. Aluminum Sulfate (alum)

6.3.2 Describe the characteristics of the chemicals (metal salts) used for phosphorus removal.

1. Ferric Chloride
  2. Ferrous Chloride
  3. Ferrous Sulfate
  4. Aluminum Sulfate (alum)
1. Ferric Chloride ( $\text{FeCl}_3$ ).
    - Acidic (may lower pH) and alkalinity.
    - Very corrosive.
    - Fume-producing.
    - Supplied 33-36% solution (11-13% iron).
    - Several grades available.
    - Stains concrete and other materials.
    - Can affect UV disinfection.
    - May affect effluent chloride.
  2. Ferrous Chloride ( $\text{FeCl}_2$ )
    - Acidic (may lower pH) and alkalinity.
    - Very corrosive.
    - Fume-producing.
    - Supplied as 18-28% solution (8-13% iron).
    - Stains concrete and other materials.
    - May affect effluent chloride.
    - May affect UV disinfection.
    - Potential impurities.
  3. Ferrous Sulfate ( $\text{FeSO}_4$ )
    - Acidic (may lower pH) and alkalinity.
    - Very corrosive.
    - Fume-producing.
    - Supplied as 23-25% solution (5-7% iron).
    - Stains concrete and other materials.
    - Should be stored in indoor heated space.
    - May affect UV disinfection.
    - Potential impurities.

4. Aluminum Sulfate (alum)  $Al_2(SO_4)_3$
- Acidic (may lower pH) and alkalinity.
  - Moderately corrosive.
  - 49% aluminum sulfate (8-9% aluminum) in liquid form.
  - Also available in dry form (powder). Must be mixed with water before use.
  - Very temperature sensitive in liquid form (must be kept above freezing).
  - Clear, light green, or yellow liquid.

6.3.3 Describe the use of polymers in phosphorus removal.

Polymers can be used as a supplement to enhance phosphorus removal through coagulation-improved settling. Polymers are usually added prior to secondary clarifiers. Improved solids and phosphorus coagulation in final clarifiers would improve secondary clarifier performance.

6.3.4 Describe crystallization characteristics of phosphorus removing chemicals.

As the percent of product increases, the temperature at which it crystallizes at will increase.

Ferric Chloride ( $FeCl_3$ )

- 42°F at 35% solution

+20°F at 42% solution

Ferrous Chloride ( $FeCl_2$ )

+28°F at 25% Solution

+42°F at 35% Solution

Ferrous Sulfate ( $FeSO_4$ )

+42°F at 25% Solution

Aluminum Sulfate ( $Al_2(SO_4)_3$ )

+32°F at 8% aluminum sulfate

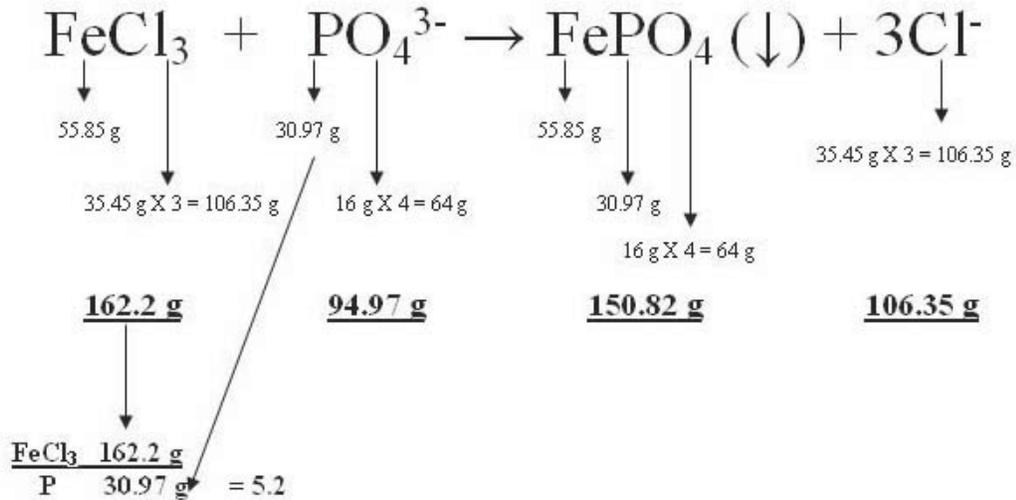
Crystallization is to be avoided because it is difficult to redissolve, plugs pipes and equipment, and forms a solid layer in storage tanks making its removal difficult. Room temperatures should be kept warm enough to avoid crystallization

6.3.5 Describe the chemical reaction of the ferric chloride with phosphorus. See Figure 6.3.5.1 below.

Graphic courtesy of Jeremy Cramer, Stevens Point

Figure 6.3.5.1

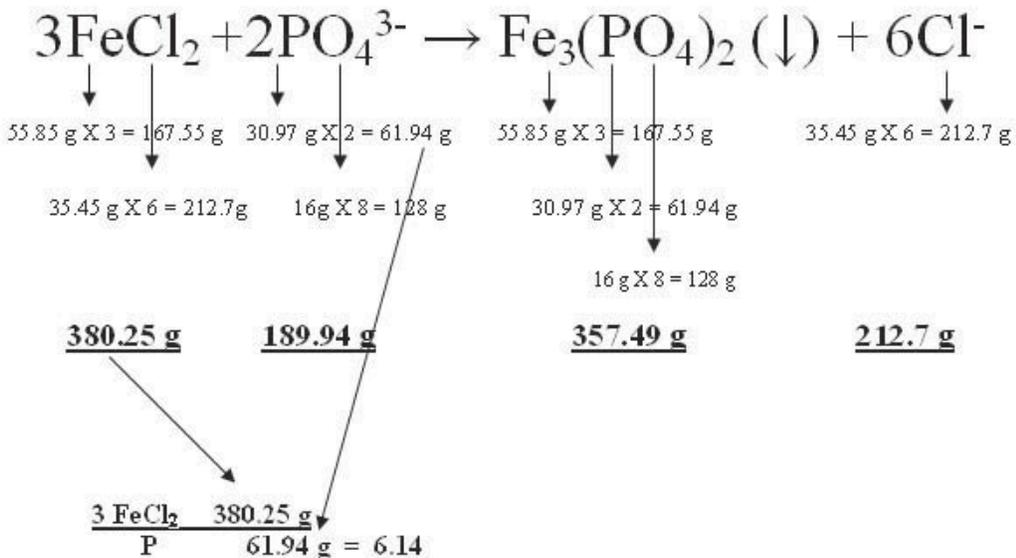
Reaction for the precipitation of phosphorus with Ferric Chloride



6.3.6 Describe the chemical reaction of the ferrous chloride with phosphorus. See Figure 6.3.6.1 below. Graphic courtesy of Jeremy Cramer, Stevens Point.

Figure 6.3.6.1

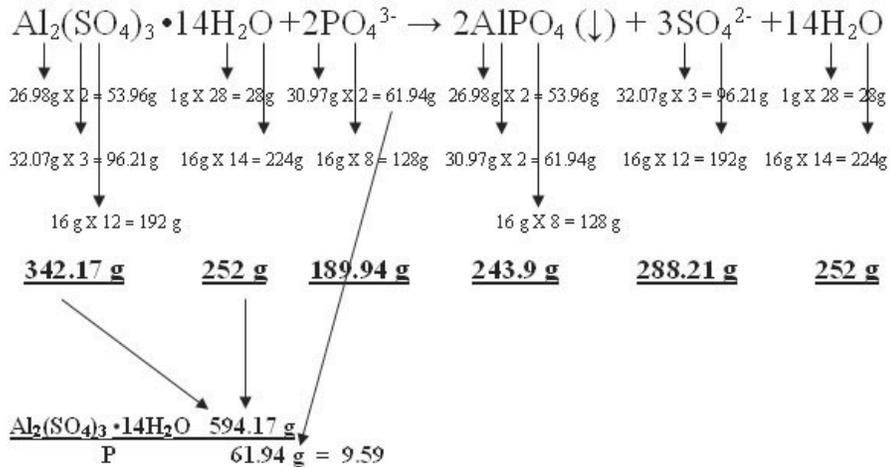
Reaction for the precipitation of phosphorus with Ferrous Chloride



6.3.7 Describe the chemical reaction of the aluminum sulfate (alum) with phosphorus. See figure 6.3.7.1 below. Graphic courtesy of Jeremy Cramer, Stevens Point.

Figure 6.3.7.1

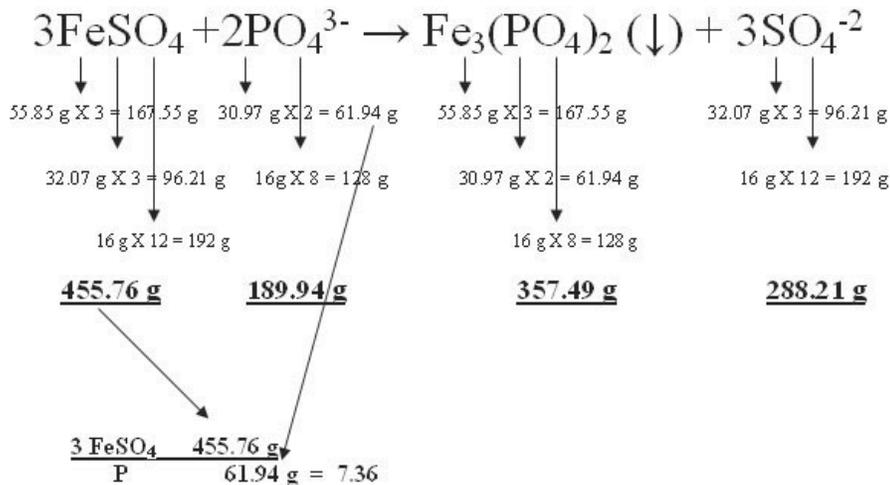
Reaction for the precipitation of phosphorus with Alum



6.3.8 Describe the chemical reaction of the ferrous sulfate with phosphorus. See Figure 6.3.8.1 below. Graphic courtesy of Jeremy Cramer, Stevens Point.

Figure 6.3.8.1

Reaction for the precipitation of phosphorus with Ferrous Sulfate



6.3.9 Summarize the information of the chemicals (metal salts) used for phosphorus removal. See Figure 6.3.9.1 & 6.3.9.2 below. Graphic courtesy of Jenchie Wang, Symbiont.

Figure 6.3.9.1

Chemical Compound	Ferric Chloride	Aluminum Sulfate (Alum)
A. Formula	FeCl <sub>3</sub>	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> • 14H <sub>2</sub> O
B. Molecular Weight (g/mole)	162.5	594
C. Typical Reaction With Phosphorus	FeCl <sub>3</sub> + PO <sub>4</sub> <sup>-3</sup> → FePO <sub>4</sub> ↓ + 3Cl <sup>-</sup>	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> • 14 H <sub>2</sub> O + 2PO <sub>4</sub> <sup>-3</sup> → 2AlPO <sub>4</sub> ↓ + 3SO <sub>4</sub> <sup>-2</sup> + 14 H <sub>2</sub> O
D: Mole Ratio (Metal : P)	1:1	1:1
E. Weight Ratio (Metal: P)	1.8 : 1	0.87 : 1
F. Mole Ratio (Metal Compound : P)	1:1	1:2
G. Weight Ratio (Metal Compound : P)	5.2:1	9.6:1
H. Commercial Strength in Solution	33 - 36%	48 - 50%
I. Percent of Active Ingredient (Metal)	11 - 13%	8 - 9%
J. Specific Gravity	1.37 @ 35%	1.335 @ 48.5%
K. Amount (Gallons) of Commercial Strength Chemical Solution Required to Remove 1 Pound of Phosphorus Based on 1x Stoichiometric Reaction	1.26 ~ 1.38	1.73 ~ 1.80

Figure 6.3.9.2

Chemical Compound	Ferrous Chloride	Ferrous Sulfate
A. Formula	FeCl <sub>2</sub>	Fe SO <sub>4</sub> • 7H <sub>2</sub> O
B. Molecular Weight (g/mole)	127	278
C. Typical Reaction With Phosphorus	3FeCl <sub>2</sub> + 2PO <sub>4</sub> <sup>-3</sup> → Fe <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> ↓ + 6Cl <sup>-</sup>	3FeSO <sub>4</sub> 7H <sub>2</sub> O + 2PO <sub>4</sub> <sup>-3</sup> → Fe <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub> ↓ + 3SO <sub>4</sub> <sup>-2</sup>
D: Mole Ratio (Metal : P)	3:2	3:2
E. Weight Ratio (Metal: P)	2.7 : 1	2.7 : 1
F. Mole Ratio (Metal Compound : P)	3:2	3:2
G. Weight Ratio (Metal Compound : P)	6.1:1	13.5 :1
H. Commercial Strength in Solution	18 - 28%	23 - 25%
I. Percent of Active Ingredient (Metal)	8 - 13%	5 - 7%
J. Specific Gravity	1.40 @ 25%	1.140 @ 25%
K. Amount (Gallons) of Commercial Strength Chemical Solution Required to Remove 1 Pound of Phosphorus Based on 1x Stoichiometric Reaction	1.86 ~ 2.90	5.68 ~ 6.17

## Section 6.4 - Performance Limiting Factors

6.4.1 Describe the effect of wastewater characteristics on phosphorus removal.

Actual chemical usage depends on the competing reactions and wastewater characteristics such as pH, alkalinity and very fine particulate materials (colloids). Wastewater characteristics and competing chemical reactions in the wastewater between the metal salt and phosphorus will result in the need for increased metal salt addition above what was calculated. Biological removal of phosphorus in upstream processes could result in a decreased amount of metal salt addition than calculated. Sampling phosphorus concentrations just upstream of the chemical dose point will help in fine-tuning chemical feed rates.

6.4.2 Explain the importance of mixing in chemical phosphorus removal.

Good mixing ensures uniform dispersion of metal salts and efficient chemical use. Overdosing with the metal salt can partially compensate for poor mixing.

Ideally high intensity mixing at the dose point would be followed by a mixed flocculation zone. However few treatment plants are designed with rapid mix basins. More typically metal salts are added at locations where turbulence occurs such as at pump suction lines, mechanical or aerated grit basins, flow-splitting structures, aerated flow distribution channels, or at hydraulic jumps in Parshall flumes.

A flocculation zone should provide sufficient detention time (15 to 20 minutes) to complete the reaction. Gentle mixing promotes flocculation. The enlarged center feed well on a flocculating clarifier provides such a flocculation zone. Where a flocculation zone is not provided metal salts should be added far enough upstream of a clarifier to provide adequate reaction time.

6.4.3 Explain how inflow and infiltration (I/I) affects chemical phosphorus removal efficiency.

Infiltration and inflow (I/I) of clear water into sanitary sewers can change the characteristics of the influent wastewater. If the influent wastewater is diluted by I/I, a chemical feed system that is flow-paced will deliver more chemical than is needed. Excessive I/I can cause peak flow rates that reduce the detention time in the treatment plant. Reduced detention time can directly effect phosphorus removal by inhibiting flocculation and settling. Phosphorus is removed from the treatment plant with the waste activated sludge, therefore solids carryover from overloaded clarifiers will increase effluent phosphorus.

## **Chapter 7 - Operation and Maintenance**

### **Section 7.1 - Methods**

7.1.1 List the methods used to determine the amount of phosphorus removed from chemical storage tanks.

1. Ultrasonic Sensors
2. Sight Glasses
3. Scales
4. Bubbler Tubes

This monitoring equipment should be cleaned and maintained for accuracy of readings. Sensors and scales should be calibrated as recommended by the O&M manual.

7.1.2 Discuss the following dose points for phosphorus removal chemicals and polymer.

Metal salt additives requires good mixing to provide effective contact of the chemical with phosphorus. The dose point may depend on facility design and mixing capability.

A. Prior to primary clarification

Advantages:

- Metal salt addition upstream of primary clarifiers enhances suspended solids and BOD removal. This reduces loading to the aeration basin.
- Odor control (especially iron salts).
- Convenience and mixing capability.
- Iron compounds may help balance nutrients in anaerobic digester.
- May reduce struvite formation.

Disadvantages:

- The result in greater chemical usage.
- May require additional chemical addition downstream.
- May result in higher biosolids production.
- Could affect nutrient ratio and pH for biological treatment.
- Target dosages can be variable due to competing reactions in the primary clarifier and secondary release in the biological treatment system.

B. Addition to secondary treatment (aeration basins)

Advantages:

- Good mixing in aerated basins or lagoons.
- $\text{Fe}^{+2}$  is oxidized to  $\text{Fe}^{+3}$  thus improving reaction with phosphate ( $\text{PO}_4^{-3}$ ).
- Orthophosphates are readily available.
- Convenience.

Disadvantages:

- Not recommended for attached growth systems.
- Could effect pH, alkalinity and nutrient ratio.
- Not recommended for unmixed ponds/lagoons.
- Iron discoloration of structures and equipment.

C. Prior to final clarification

Advantages:

- Efficient and high level of removal because most phosphorus is the orthophosphate form.
- Enhances final settling.
- Less interfering or competing reactions.
- Cost effectiveness.

Disadvantages:

- Inadequate mixing.

- 7.1.3 Discuss the chemical storage precautions for a prolonged shutdown (greater than 1 month) of a chemical feed system.

The chemical metering pump and associated piping should be flushed with clean water. Maintain the proper temperature for any stored chemical.

- 7.1.4 Describe factors that effect the amount of metal salt needed to remove phosphorus in a pond system.

The initial estimate of the metal salt dose needed to remove phosphorus in a pond system can be calculated in the same manner as for an activated sludge system. As with activated sludge, competing reactions will require more metal salt than the theoretical dose. Total phosphorus in a pond includes soluble and particulate phosphorus and phosphorus contained in algal cells. While the metal salt will react with orthophosphate to create an insoluble precipitate, algae and particulates will also settle with precipitate.

- 7.1.5 Discuss the ways in which phosphorus removal chemicals can be added at a pond or lagoon system.

For continuous dosing, metal salts to remove phosphorus are usually added to the last pond or lagoon where the precipitation reaction and settling can occur. The chemical should be added where good mixing of the chemical with the wastewater can be achieved, such as the upstream manhole prior to the last pond or just before an aerator. For batch dosing of aluminum sulfate (alum), in fill and draw systems, some operators use a small motorboat and manually apply the alum where the propellor can provide the mixing.

- 7.1.6 Explain how a pond is "batch treated" using a small motorboat or pontoon type boat.

Alum is typically the phosphorus removal chemical applied to a pond by boat. The boat is fitted with a tank to hold the chemical. The chemical drains by gravity to the propeller area where it is mixed into the pond. The boat travels and applies chemical in a gridwork pattern across the entire pond surface. The floc that forms is allowed to settle for 24-48 hours and a sample of the treated pond is taken to assure it meets effluent limits before the pond is discharged. This can be an inexpensive and effective method to treat and remove phosphorus from ponds and lagoons. Care must be taken in shallow ponds when boat propellers are used for mixing so as to not rile up the solids settled in the pond or damage the liner.

## **Section 7.2 - Equipment**

- 7.2.1 List the basic equipment used in the process of removing phosphorus by chemical precipitation.

- A. Chemical storage tanks.
- B. Piping system.
- C. Chemical feed pumps.
- D. Electrical controls.
- E. Monitoring equipment of chemical storage and usage.

7.2.2 Describe the function and the most probable location in a phosphorus removal system of each of the following.

A. Back Pressure Valve:

The back pressure valve is located in the discharge piping of the chemical metering pump. The purpose of the back pressure valve is to maintain a constant discharge pressure on the chemical metering pump. This ensures that the chemical output will remain the same as the level in the storage tank changes.

B. Pressure Relief Valve:

The pressure relief valve is part of the chemical metering pump discharge line. The pressure relief valve is set to open at a discharge pressure normally 20-25 psi over the back pressure valve setting. If the discharge pressure increases to a pressure over the pressure relief valve setting caused by a blockage of the discharge line, the relief valve will open and release its pressure back into the chemical storage tank.

C. Chemical Metering Pump Suction Check Valve (positive displacement pump):

The chemical metering pump suction valve is located on the bottom of the chemical metering pump head.

The suction valve allows the flow of chemical into the chemical metering pump head cavity during the suction stroke. During the discharge stroke the suction valve stops the chemical within the pump cavity from going back out of the suction valve.

D. Chemical Metering Pump Discharge Check Valve (positive displacement pump):

The chemical metering pump discharge valve is located on the top of the chemical metering pump head.

The discharge valve does not allow the chemical to flow back into the pump head cavity during the suction stroke while allowing the flow of chemical out of the pump cavity during the discharge stroke.

E. Pulsation Dampner:

The pulsation dampner is part of the chemical metering pump discharge line.

The pulsation dampner acts as a shock absorber on the discharge line. The dampner reduces the discharge pressure surge on the discharge line during the discharge stroke of the chemical metering pump.

F. Backflow Preventer:

A device installed on a water supply line that will prevent backflow of water or chemical back into the water supply system.

- 7.2.3 Discuss how chemical metering pumps can be controlled to feed chemical.
- A. Manual
  - B. Automatic
    - 1. Flow
    - 2. Time
    - 3. Residual
- 7.2.4 Discuss the types of chemical feed pumps used in chemical precipitation of phosphorus. Positive displacement and peristaltic feed pumps are commonly used for feeding metal salts. Either pumps can be adjusted automatically, allowing for the appropriate dosage.

### **Section 7.3 - Handling and Storage**

- 7.3.1 List the materials and conditions for the storage and feeding of the following chemicals:
- A. Iron Salts:  
Ferric chloride, ferric sulfate, and ferrous sulfate should be stored in tanks made of fiberglass reinforced plastic (frp), polyethylene, or saran-lined steel. The tank must be surrounded with a containment area in case of a leak. Feed pumps should be compatible with the chemicals being used. Schedule 80 PVC piping and valving is commonly used. The storage temperature of metal salts is an important factor to remember.
  - B. Aluminum Salts:  
Aluminum sulfate should be stored in tanks made of fiberglass reinforced plastic (frp), polyethylene, or 316 stainless steel. The tank must be surrounded with a containment area in case of a leak. Feed pumps should be compatible with the chemicals being used. Schedule 80 PVC and stainless steel piping and valving is commonly used. The storage temperature of metal salts is an important factor to remember.
- 7.3.2 Discuss ways to control corrosion from phosphorus removal chemicals.
- A. Vent storage tanks to the outside of the building and away from equipment and air intakes.
  - B. Select chemically resistant materials.
  - C. Ensure proper ventilation of the storage room to the outside.
  - D. Keep equipment and area clean.
  - E. Maintain proper chemically resistant paint or coatings.
- 7.3.3 Discuss what needs to be checked or done when switching from one phosphorus removal chemical to another.
- Because of their characteristics, the different phosphorus removal chemicals should not be mixed. The storage tanks' pumps and piping must be drained and flushed with water and the water removed before changing to another chemical. The operator must make sure that the pump and the materials used for seals, valves, piping, and storage are compatible with the chemical being fed.

Operators should contact their consultant for changeover assistance.

The capacity of the chemical metering pump must be sized properly for the new phosphorus removal chemical. New feed rates need to be calculated and feed pump adjusted accordingly.

The storage temperature of metal salts is an important factor to remember.

## **Section 7.4 - Preventive Maintenance**

7.4.1 Describe maintenance requirements for chemical phosphorus removal systems.

- A. Inspect tanks and piping for cracks, leaks, and metal salt deposits on a regular basis. Repair as soon as possible.
- B. Check equipment for corrosion from chemical fumes. Locate source of fumes and repair or replace corroded parts, if necessary.
- C. Check for developing line blockage by monitoring chemical metering pump discharge pressure. Consult with chemical supplier.
- D. Confirm the heating and ventilation systems are working properly. Repair if necessary.

7.4.2 List the preventive maintenance procedures for chemical feed pumps.

Operators should always read the manufacturer's instruction manual and follow the recommendations.

- A. Check and change oil in the gear case as suggested in the manufacturers O&M manual.
- B. Check the seals and fittings for leakage. Repair or replace as needed with components intended for the type of chemical being fed.
- C. Keep pump and motor clean.
- D. For positive displacement pumps, replace inlet and outlet check valves and pump diaphragm as recommended by the manufacturer.
- E. For peristaltic pumps, replace pump tubing as recommended by manufacturer.

## **Section 7.5 - Biosolids Issues**

7.5.1 Discuss how much more biosolids could be expected to be produced using chemical precipitation for phosphorus removal.

Additional biosolids will be generated when chemical phosphorus removal is used. Increases in biosolids can vary depending upon the influent phosphorus, the chemical used and the application point. Overall, plant biosolids increases are commonly 10-25%.

7.5.2 Discuss the build-up of sludge in lagoons/ponds using chemicals for phosphorus removal.

Solids will accumulate in the the pond where precipitates form and settle. The amount of chemical sludge produced is 7.5 mg chemical sludge per mg phosphorus removed for alum, and 10mg chemical sludge per mg phosphorus removed for iron. Sludge depths should be measured annually and sludge removed as needed to avoid any release of the

phosphorus from the settled sludge and organic material.

## **Chapter 8 - Monitoring, Process Control, and Troubleshooting**

### **Section 8.1 - Sampling & Testing**

- 8.1.1 Describe how an operator or municipality could identify influent phosphorus loading to a treatment plant.
- Operators can survey businesses and industries for phosphorus containing products they use or produce. They can also sample for likely sources of phosphorus by sampling wastewater discharges, and identifying the industries which have high concentrations of phosphorus. Regular sampling of industries and the establishment of a phosphorus removal surcharge through a sewer use ordinance will encourage waste minimization.
- 8.1.2 Identify some important sampling locations for determining phosphorus concentrations in a wastewater treatment plant.
- A. Influent - This sample will determine the amount of phosphorus entering the plant.
  - B. Sidestreams - This sample identifies internal sources of phosphorus.
  - C. Effluent - This sample will determine the amount of phosphorus remaining after the treatment process.
- 8.1.3 Identify a test method that can be used for process control other than total phosphorus digestion methods.
- A test kit for reactive phosphorus (orthophosphate) may be used to estimate phosphorus concentrations for process control. These tests are colorimetric tests that allow for fast results to enable timely process control adjustments.
- 8.1.4 Describe the method to preserve samples for phosphorus at a later date.
- Samples which are not to be analyzed on the day they are collected must be preserved with sulfuric acid to a pH of <2, cooled to 6°C or less but not frozen and can then be stored up to 28 days.

### **Section 8.2 - Process Understanding & Interpretation**

- 8.2.1 Describe the difference between total phosphorus and reactive phosphorus (orthophosphate).
- Total phosphorus is the analytical result following a rigorous acid digestion of a wastewater sample. This typically includes phosphorus associated with suspended solids and organically bound forms, as well as more soluble and reactive forms.
- Phosphorus occurs mostly as phosphates in wastewater. Phosphates that respond to colorimetric tests without digestion of the sample are termed "reactive phosphorus", which is largely measured as orthophosphate (H<sub>2</sub>PO<sub>4</sub>, HPO<sub>4</sub>, PO<sub>4</sub>). Orthophosphate can be thought of as the form of phosphorus that is dissolved, reactive, and most readily available to microorganisms and aquatic life.

- 8.2.2 Discuss why the optimization of chemical addition for phosphorus removal is important.  
Too low a dose of metal salt can result in variable effluent phosphorus concentrations as well as violations of permit limits. Too high a dose can result in wasted chemical, increased chemical costs, biological (pH/alkalinity) problems, and plugging problems in piping/valves.
- 8.2.3 Discuss the significance of the forms of phosphorus in wastewater.  
Total phosphorus consists of soluble and particulate phosphorus. Metal salts function to primarily remove soluble phosphorus, which is measured as orthophosphate. The effluent total suspended solids should be minimized in order to ensure meeting a phosphorus limit.
- 8.2.4 Discuss the difference between theoretical calculated dosage and the actual applied dosage in meeting effluent phosphorus limits.  
Wastewater characteristics and competing chemical reactions in the wastewater will result in the need for increased metal salt addition above what was calculated. Conversely, biological removal of phosphorus in upstream processes could result in decreased amounts of metal salt addition than calculated. Sampling phosphorus concentrations just upstream of the chemical dose point will help in fine-tuning chemical feed rates.
- 8.2.5 Describe the effect algae can have on effluent suspended solids and phosphorus being discharged from a pond/lagoon.  
In a treatment system such as a pond or lagoon, phosphorus is a primary nutrient utilized by algae for growth. Excess phosphorus can result in algal blooms. Algae carried out with the effluent can not only result in effluent suspended solids violations but may also contain phosphorus associated with algal cells. It is important that when using a metal salt to precipitate out phosphorus, excess algae is not discharged. This will ensure meeting effluent limits.

### **Section 8.3 - Side Streams**

- 8.3.1 Discuss common wastewater treatment sidestreams and their potential effect on phosphorus removal.  
Sidestreams are flows that are recycled back through the treatment plant from other unit processes or operations. Most commonly, sidestreams originate from biosolids treatment, processing and dewatering such as decants from digesters and sludge storage tanks and filtrates off dewatering belts, presses, and thickeners. Sidestreams with elevated levels of phosphorus will affect the chemical dosage requirements of the metal salt being applied. Sampling all sidestreams for phosphorus is critical for good process control and proper chemical addition.

### **Section 8.4 - Corrective Actions**

- 8.4.1 State the possible causes and corrections for exceeding effluent phosphorus limits after metal salt addition.  
POSSIBLE CAUSE: Chemical metering equipment is not working properly.  
CORRECTION: Inspect and ensure all chemical metering equipment and piping is

operational and performing as required.

POSSIBLE CAUSE: Too low a dose.

CORRECTION: Wastewater characteristics and competing reactions require more chemical than calculated. Add more chemical, but no more than needed, to meet the effluent limit.

POSSIBLE CAUSE: Influent phosphorus loads are higher than normal.

CORRECTION: Sample influent wastewater for phosphorus. Recalculate the dosage rate. Locate sources of high phosphorus and try to reduce.

POSSIBLE CAUSE: Dose point not effective.

CORRECTION: Evaluate if the metal salt should be applied at a different location.

POSSIBLE CAUSE: High effluent suspended solids.

CORRECTION: Review plant operations and determine why effluent solids are elevated (I/I, old sludge, clarifier problems, etc).

POSSIBLE CAUSE: Sidestream phosphorus.

CORRECTION: Sample sidestreams for phosphorus and if high, reduce sidestream flows and phosphorus loadings accordingly. Modify biosolids treatment and dewatering operations if possible. Treat sidestreams with metal salts if needed.

## **Chapter 9 - Safety**

### **Section 9.1 - Regulations & Procedures**

- 9.1.1 Discuss the importance of maintaining chemical delivery, storage, and usage records. All phosphorus removal chemicals are considered hazardous materials. Therefore all amounts delivered, stored, and used need to be accounted for. Material Safety Data Sheets (MSDS) are required to be kept on-site and available. Contact the DNR in event of a spill.
- 9.1.2 Discuss the reporting requirements for phosphorus removal chemicals under Federal, State, and Local laws.
- In order to comply with Sections 311& 312- Community Right-to-Know Requirements of Title III of the Superfund Amendments and Reauthorization Act (SARA Title III), Wisconsin Statute 166.20 and Chapter SERB 1 of the Wisc. Admin., Code, the Wisconsin State Emergency Response Board requires that all facilities having a hazardous chemical with Material Safety Data Sheets (MSDS) present at their facility in large volumes (greater or equal to 500 lbs) to annually submit a Tier two, Emergency and Hazardous Chemical Inventory Form. If there are questions about the need to report hazardous chemical storage, contact your county hazardous waste coordinator.

The laws require that the chemical inventory report be annually sent to:

- State Emergency Response Commission.
- Local Emergency Planning Committee.

-Local Fire Department.

The report shall include the following information:

- 1) Chemical and common name of the chemical.
- 2) Estimate of maximum amount of chemical at the facility in the proceeding year.
- 3) Estimate of the average daily amount of chemical at the facility in the proceeding year.
- 4) Description of the manner of storage.
- 5) Location of the stored chemical at the facility.

- 9.1.3 Discuss preventative spill measures and procedures when handling phosphorus removal chemicals.

Storage tanks must have secondary containment that equals the volume of the storage tank. During unloading of delivery vehicles, place containment pails under potential leak points and when uncoupling fill lines. Inspect and maintain fill lines and valves. Inspect storage tank and hardware for integrity.

Provide on-site containment equipment such as absorbent boom, sandbags, etc., and seal your yard/storm drains to prevent off-site loss of chemical. Pay attention to what you are doing.

- 9.1.4 Discuss what should be done in the event of a phosphorus removal chemical spill.

1. Any spill of hazardous material should be reported to DNR within 24 hours and to the local emergency response agencies.
2. Contact CHEMTREX for further spill response and cleanup advice.

- 9.1.5 Discuss the proper procedure for entering a chemical storage tank.  
FOLLOW ALL CONFINED SPACE ENTRY PROCEDURES!

## **Section 9.2 - Equipment**

- 9.2.1 Describe the safety equipment to be used when working with phosphorus removal chemicals.

The operator should wear protective clothing that includes acid-resistant gloves, a rubber apron, and a face shield. Emergency shower and eyewash should be nearby. All ventilation systems should be properly working. When handling dry products, respiratory and eye protection should be used.

## **Section 9.3 - Chemical Considerations**

- 9.3.1 Discuss the potential hazardous reactions which may result if the following chemicals are mixed together.

A. Ferric chloride and sodium hypochlorite. The mixing of ferric chloride and sodium hypochlorite will cause a uncontrollable release of

chlorine gas.

- B. Aluminum sulfate and sodium hypochlorite. The mixing of aluminum sulfate and sodium hypochlorite will cause an uncontrollable release of chlorine gas.
- C. Ferric chloride and aluminum sulfate. The mixing of ferric chloride and aluminum sulfate will cause a exothermic reaction (releases heat) and a release of acid fumes. The reaction is caused by the different types of acids that are used in the manufacturing of the metal salts. Ferric chloride is manufactured with hydrochloric acid and aluminum sulfate is manufactured with sulfuric acid.

9.3.2 Describe the hazards associated with phosphorus removing chemicals.

The iron metal salts are acidic, highly corrosive and produce fumes. Alum is mildly corrosive and produces fumes.

Alum, upon evaporating after a spill can be very slippery. Polymers are slippery when wet.

## **Chapter 10 - Calculations**

### **Section 10.1 - Calculations**

10.1.1 Given data, calculate the phosphorus loading to a plant in pounds per day.

GIVEN:

Flow = 2.7 MGD

Influent total phosphorus = 6.9 mg/L

FORMULA:

Pounds/day = Flow (MGD) × Influent phosphorus (mg/L) × 8.34 lbs/MG/mg/L

SOLUTION:

Pounds/day = 2.7 MGD × 6.9mg/L × 8.34 lbs/MG/mg/L  
= 155 pounds/day

10.1.2 Using metal salt chemical data, theoretically calculate the amount of chemical salt solution to add in gallons per day to remove phosphorus.

GIVEN:

Influent flow = 2.0 MGD

Influent phosphorus = 8 mg/L

Metal salt solution

Specific gravity = 1.40

Percent (%) metal in solution = 12.5%

Metal to phosphorus removal ratio (weight basis) = 1.8:1.0

FORMULAS & SOLUTION:

(1) Determine the amount of influent phosphorus to remove

$$\begin{aligned}\text{lbs phosphorus to remove} &= (\text{flow in MGD}) \times (\text{phosphorus concentration in mg/L}) \times (8.34 \text{ lbs/MG/mg/L}) \\ &= (2.0 \text{ MGD}) \times (8 \text{ mg/L}) \times (8.34 \text{ lbs/MG/mg/L}) \\ &= 133 \text{ lbs phosphorus}\end{aligned}$$

(2) Determine the pounds of metal salt in a gallon of solution knowing the specific gravity.

$$\begin{aligned}\text{lbs metal salt/gallon} &= (\text{specific gravity}) \times (8.34 \text{ lbs/gal}) \\ &= (1.40) \times (8.34 \text{ lbs/gal}) \\ &= 11.68 \text{ lbs metal salt/gal}\end{aligned}$$

(3) Determine the pounds of actual metal in a gallon of metal salt solution with a certain % metal content.

$$\begin{aligned}\text{lbs metal/gallon metal salt solution} &= (\text{lbs of metal salt/gal}) \times (\% \text{ metal}) \\ &= (11.68 \text{ lbs}) \times (0.125) \\ &= 1.5 \text{ lbs metal/gal}\end{aligned}$$

(4) Look up removal ratio for the metal salt being used.

(5) Determine the pounds of metal needed to remove the incoming pounds of phosphorus.

$$\begin{aligned}\text{lbs/day of metal to add per lb phosphorus to remove} &= (\text{removal ratio}) \times (\text{Influent lbs of phosphorus}) \\ &= (1.8) \times (133 \text{ lbs phosphorus}) \\ &= 239 \text{ lbs/day metal to add}\end{aligned}$$

(6) Determine the gallons per day of metal salt solution with a certain % metal content to thus add.

$$\begin{aligned}\text{Gallons of metal salt solution to add} &= (\text{lbs of metal to add}) \div (\text{lbs metal/gal}) \\ &= (239 \text{ lbs metal}) \div (1.5 \text{ lbs metal/gal}) \\ &= 159 \text{ gallon/day of metal salt solution}\end{aligned}$$

10.1.3 The Wisconsin Department of Natural Resources NR 101 Wastewater Fee Program assesses an annual fee for the amount (in pounds) of phosphorus discharged each year. The rate for phosphorus is 34 cents (\$0.34) per pound discharged times an adjustment factor of 2.451. Given a total annual amount of phosphorus discharged, calculate the NR 101 wastewater fee.

GIVEN:

Total phosphorus discharged = 6950 pounds

Rate = 0.34 dollars per pound

Adjustment Factor = 2.451

FORMULA:

$$\begin{aligned}\text{Amount Due} &= (\text{lbs P discharged}) \times (\text{rate}) \times (\text{Adj. Factor}) \\ &= (6950 \text{ lbs}) \times (\$0.34/\text{lb}) \times (2.451) \\ &= \$5792\end{aligned}$$

- 10.1.4 Given the specific gravity of a metal salt solution and actual % metal content, determine the pounds of actual metal in a gallon of metal salt solution.

GIVEN:

Ferric chloride solution with a specific gravity of 1.40 and 12.5% iron content.

FORMULAS:

$$\begin{aligned}\text{lbs metal salt/gallon solution} &= (\text{Specific Gravity}) \times 8.34 \text{ lbs/gal} \\ &= 1.40 \times 8.34 \text{ lbs/gal} \\ &= 11.7 \text{ lbs/gallon}\end{aligned}$$

$$\begin{aligned}\text{lbs metal/gallon metal salt solution} &= (\text{lbs metal salt/gallon}) \times (\% \text{ metal}) \\ &= (11.7 \text{ lbs/gal}) \times (0.125) \\ &= 1.46 \text{ lbs/gallon}\end{aligned}$$

- 10.1.5 Given data calculate the phosphorus loading in pounds from a sidestream.

GIVEN:

Sidestream flow = 60,000 gallons per day  
Phosphorus Concentration = 25 mg/L

FORMULA:

$$\begin{aligned}\text{Sidestream Phosphorus Loads (lbs)} &= \\ &= (\text{Sidestream Flow in MG}) \times (\text{P Concentration in mg/L}) \times 8.34 \text{ lbs/MG/mg/L} \\ &= (0.060 \text{ MG}) \times (25 \text{ mg/L}) \times 8.34 \text{ lbs/MG/mg/L} \\ &= 12.5 \text{ lbs phosphorus per day}\end{aligned}$$

## References and Resources

**1. BIOLOGICAL NUTRIENT REMOVAL (BNR) OPERATION IN WASTEWATER TREATMENT PLANTS (Primary Resource)**

(2006) Manual of Practice No. 29. Water Environment Federation and the American Society of Civil Engineers/Environmental and Water Resources Institute. McGraw-Hill Publishers.

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**2. PHOSPHORUS AND NITROGEN REMOVAL FROM MUNICIPAL WASTEWATER PRINCIPALS (Primary Resource)**

(1991) 2nd Edition. Richard Sedlak, Editor. The Soap and Detergent Association. Lewis Publishers

Available through inter-library loan at <http://aqua.wisc.edu/waterlibrary>

**3. Operation of Municipal Wastewater Treatment Plants**

(2008) Manual of Practice No. 11 (6th Edition), Volume 2 – Liquid Processes. Water Environment Federation. McGraw Hill Publishers.

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**4. Operation of Wastewater Treatment Plants – A Field Study Training Program**

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**7. Optimizing BPR Plant Operations For Achieving Sustainable Low Effluent Phosphorus**

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