Wisconsin Department of Natural Resources
Wastewater Operator Certification

Nutrient Removal - Total Phosphorus

Subclass P

August 2015

Wisconsin Department of Natural Resources
Bureau of Science Services
Operator Certification Program
P.O. Box 7921, Madison, WI 53707

http://dnr.wi.gov

Preface

The Nutrient Removal – Total Phosphorus Study Guide is an important resource for preparing for the certification exam and is arranged by chapters and sections. Each section consists of key knowledges with important informational concepts you need to know for the certification exam. This study guide also serves as a wastewater treatment plant operations primer that can be used as a reference on the subject.

In preparing for the exams:
1. Study the material! Read every key knowledge until the concept is fully understood and known to memory.

2. Learn with others! Take classes in this type of wastewater operations to improve your understanding and knowledge of the subject.

3. Learn even more! For an even greater understanding and knowledge of the subjects, read and review the references listed at the end of the study guide.

Knowledge of the study guide material will be tested using a multiple choice format. Every test question and answer comes directly from one of the key knowledges.

Choosing a test date:
Before choosing a test date, consider the time you have to thoroughly study the guides and the training opportunities available. A listing of wastewater training opportunities and exam dates is available at www.dnr.wi.gov by searching for the keywords “Operator Certification”.

Acknowledgements

The Nutrient Removal – Total Phosphorus Study Guide was the result of a collaborative effort of yearlong monthly meetings of wastewater operators, trainers, consultants, the Wisconsin Wastewater Operator Association (WWOA) and the Wisconsin Department of Natural Resources (WDNR). This study guide was developed as the result of the knowledge and collective work of following workgroup members:

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Table of Contents

Part 1 - Biological Removal

Chapter 1 - Theory and Principles

Chapter 2 - Operation and Maintenance

Chapter 3 - Monitoring, Process Control, and Troubleshooting

Chapter 4 - Safety

Chapter 5 - Calculations

Part 2 - Chemical Removal

Chapter 6 - Theory and Principles

Chapter 7 - Operation and Maintenance

Table of Contents

Chapter 8 - Monitoring, Process Control, and Troubleshooting

Chapter 9 - Safety and Regulations

Chapter 10 - Calculations

Part 1 - Biological Removal

Chapter 1 - Theory and Principles

Section 1.1 - Definitions

1.1.1 Define aerobic (oxic) [O2].

Aerobic is a condition in which free and dissolved oxygen (DO) is available in an aqueous environment.

1.1.2 Define anaerobic [Ø].

Anaerobic is a condition in which free, dissolved, and combined oxygen is unavailable in an aqueous environment.

1.1.3 Define anoxic [NO2, NO3, SO4].

Anoxic is a condition in which oxygen is only available in a combined form such as nitrate (NO3), nitrite (NO2) or sulfate (SO4) in an aqueous environment.

1.1.4 Define fermentation.

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

1.1.5 Define glycogen.

Glycogen is a polysaccharide of glucose which is another energy storage inside a cell. It is present in all cells, but microorganisms which accumulate glycogen in cells during the anaerobic stage of a enhanced biological phosphorus removal (EBPR or bio-P) process are not able to perform biological phosphorus removal.

1.1.6 Define phosphate-accumulating organisms (PAO).

PAOs are microorganisms (bacteria) that uptake and store orthophosphate in excess of their biological requirements.

1.1.7 Define polyhydroxyalkanoates (PHA).

PHAs are energy-rich carbon polymers inside a bacterial cell, which are converted from readily available organic molecules such as volatile fatty acids (VFA) in the wastewater. PHAs are the intracellular energy storage of the PAOs. The PAOs utilize PHA as a energy source to uptake phosphorus from the wastewater in the aerobic zone of the EBPR.

1.1.8 Define polyphosphate (poly-P).

Poly-P is a string of phosphate (PO4) groups joined together. It is present in all cells but the PAOs are capable of accumulating excess poly-P in their cells thereby accomplishing EBPR.

1.1.9 Define selector.

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

1.1.10 Define selector hydraulic retention time (HRT).

The selector HRT, also known as hydraulic detention time, is the given time it takes wastewater, including any return flows, to pass through a tank (selector).

1.1.11 Define sludge age.

Sludge age is the length of time a particle of activated sludge stays in the treatment plant and is measured in days. In a EBPR plant, sludge age is the amount (pounds) of mixed liquor suspended solids (MLSS) in all the biological reactors divided by the suspended solids withdrawn from the system per day (pounds per day of waste activated sludge or WAS).

1.1.12 Define soluble biochemical oxygen demand (BOD).

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

1.1.13 Define substrate.

Substrate is 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 EBPR systems, VFAs are a readily available substrate used by the PAOs.

1.1.14 Define treatment facility overflow (TFO).

A TFO is a release of wastewater, other than through permitted outfalls, from a wastewater facility into a water of the state or the land surface. All TFOs must be reported to the Department of Natural Resources within 24 hours of the occurrence.

1.1.15 Define volatile fatty acids (VFA).

When organic material undergoes fermentation reactions, smaller and more readily available organic molecules are formed known as VFAs. VFAs typically found in wastewater are acetic acid (acetate) and propionic acid. VFAs provide the food for PAOs.

Section 1.2 - Wastewater Characteristics

1.2.1 List major industrial sources of phosphorus.

A. Dairies
B. Food processors
C. Metal finishers
D. Hospitals
E. Schools
F. Car washes

1.2.2 Discuss the importance of the influent biochemical oxygen demand (BOD) or chemical oxygen demand (COD) and total phosphorus ratio in enhanced biological phosphorus removal (EBPR).

The success of removing phosphorus biologically depends upon the amount of organic material, expressed as either BOD 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 (PAO). Studies of operations have shown that a BOD/phosphorus ratio of at least 20:1 or a COD/phosphorus ratio of at least 45:1 is needed for EBPR.

1.2.3 Discuss the importance of the wastewater volatile fatty acid (VFA) content in EBPR.

The organic material entering an anaerobic selector must be soluble and readily available to PAOs. The smallest molecules that organic material can be broken into are VFAs which are utilized by PAOs to form and store polyhydroxyalkanoates (PHA) 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 (CH3-COOH).

1.2.4 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 VFAs 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).

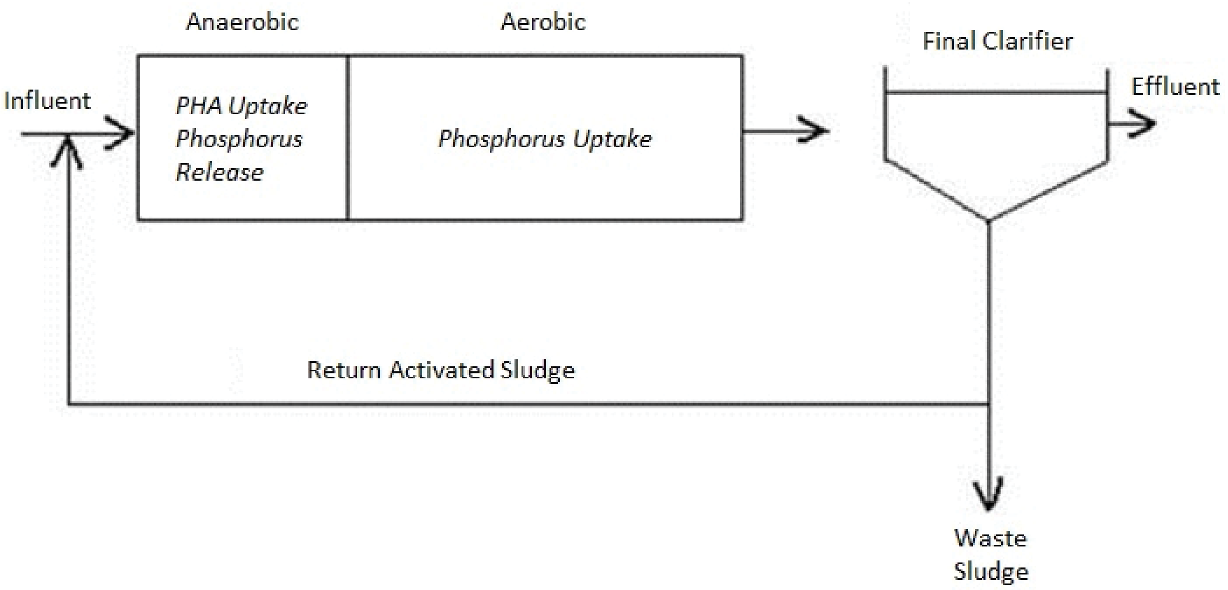
EBPR relies on the selection and proliferation of a microbial population capable of uptaking orthophosphate in greater amounts than their normal biological growth requirements.

EBPR 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).

Graphic source: Jeremy Cramer, Stevens Point

Figure 1.3.1.1

A typical EBPR reactor configuration

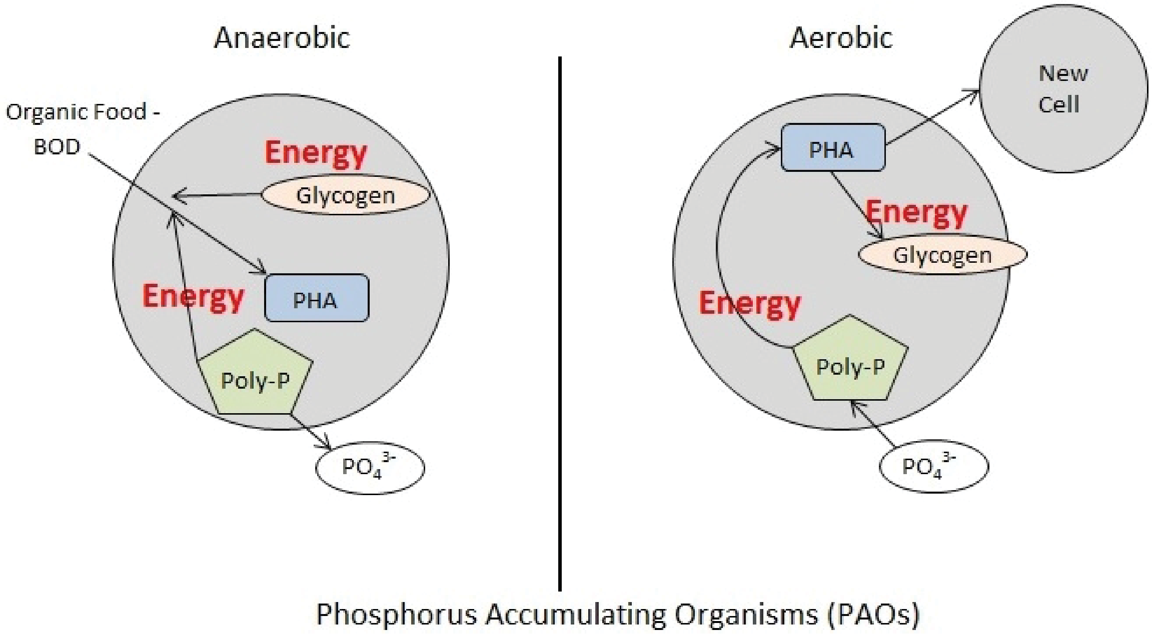


1.3.2 Describe and show the mechanism of an EBPR.

The unique feature of EBPR is the anaerobic selector used in the treatment process (see figure).

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).

PAOs use polyphosphate (poly-P) and glycogen stored in their cells as energy sources to enable them to uptake volatile fatty acids (VFA). VFAs 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).

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 polyphosphate in the aerobic zone. To replenish their stored polyphosphate, PAOs will take up excess phosphate from the mixed liquor, the mechanism of EBPR.

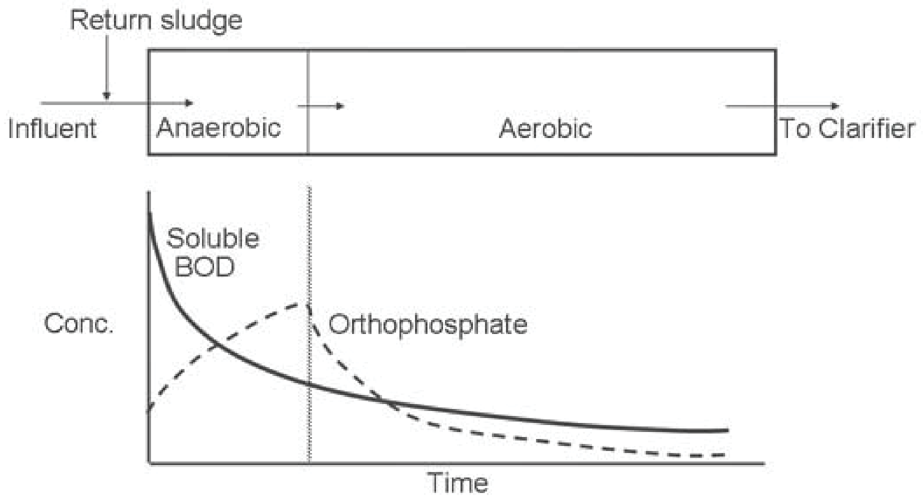
1.3.5 Describe and show the phosphorus and biochemical oxygen demand (BOD) profile through a treatment plant.

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 polyphosphate supplies in the aerobic zone, the concentration of orthophosphate in the mixed liquor will rapidly decrease (see figure).

Graphic source: Jenchie Wang, Symbiont

Figure 1.3.5.1

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



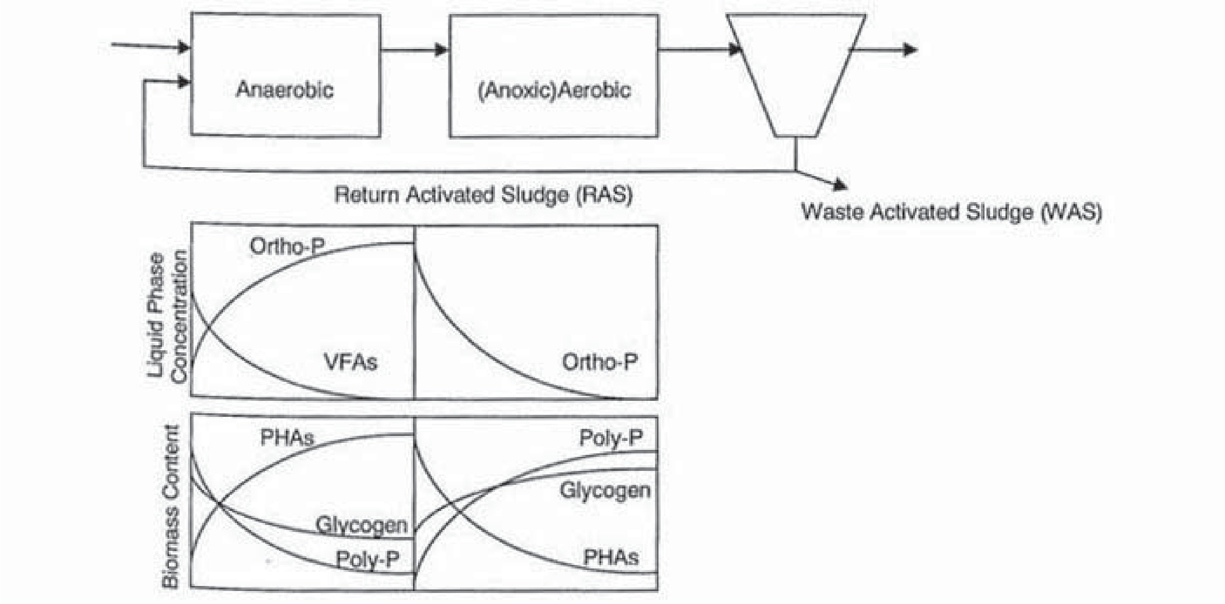
1.3.6 Describe and show the concentration profiles through the plant of glycogen, VFA, PHA, polyphosphate, and orthophosphate.

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 polyphosphate as energy sources; therefore 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 polyphosphate. To build up their supply of polyphosphate, PAOs will take up excess orthophosphate from the mixed liquor in the aerobic zone.

Figure 1.3.6.1 below (from WEF MOP 25, 2005) 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 are 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 (DO) in the anaerobic zone.

If nitrate or DO are present, uptake of volatile fatty acids (VFA) 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 (NO2, NO3, SO4). Denitrifying bacteria, under anoxic conditions, will uptake VFAs, thus decreasing the VFAs available for the phosphate-accumulating organisms (PAO).

Chapter 2 - Operation and Maintenance

Section 2.1 - Definitions

2.1.1 Define denitrification.

Denitrification is a biological process where bacteria convert nitrate (NO_3^-) to nitrogen gas (N_2) under anoxic conditions.

2.1.2 Define nitrification.

Nitrification is a biological process where nitrifying bacteria convert nitrogen, in the form of ammonia (NH_3), into nitrite (NO_2^-) and nitrate (NO_3^-) under aerobic conditions.

2.1.3 Define struvite.

Struvite is magnesium ammonium phosphate ($MgNH_4PO_4(H_2O)_6$). It forms hard, very insoluble, white, yellowish-white, or brownish-white crystals.

Section 2.2 - Reactors

2.2.1 Discuss why anoxic zones are used along with anaerobic zones as part of enhanced biological phosphorus removal (EBPR).

The recycling of nitrates to the anaerobic selector will interfere with the EBPR process, just as oxygen would. Anoxic zones are provided to denitrify ($NO_2 + NO_3 \rightarrow N_2$) recycle streams (also referred to as sidestreams). Where recycle streams contain nitrates, for example return activated sludge (RAS), anoxic zones can ensure that nitrates are not returned to the anaerobic selector.

2.2.2 Discuss the importance of selector hydraulic residence time (HRT).

HRT is a very important operational parameter in allowing enough time for EBPR reactions to take place. HRT is the contact time between the incoming influent containing the readily available organic substrate and nutrients with the microorganisms (phosphate-accumulating organisms or PAOs). The amount of volatile fatty acids (VFA) 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 to 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 HRT of an anaerobic selector can be effected by high influent flows caused by infiltration/inflow (I/I) and high RAS rates with resultant poor phosphorus removal.

2.2.3 Discuss the importance of sludge age in the treatment system on EBPR.

As with all activated sludge systems, sludge age determines how long the biomass stays in the biological part of the treatment system. Because EBPR 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 needing to take place and for the biomass to uptake excess phosphates in the aerobic basins (see key knowledge 1.3.5). Too short of sludge age and insufficient treatment can occur with resulting 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 to 30 days are likely to be observed in successful EBPR plants.

2.2.4 Discuss the different treatment configurations used for EBPR.

There are many types of EBPR systems. Some of the more common types are anaerobic/oxic (A/O), anaerobic/anoxic/oxic (A2/O), modified Bardenpho, University of Cape Town (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.

2.2.5 Describe how bacterial solids are kept in suspension in selector tanks.

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

Section 2.3 - Methods

2.3.1 List some operational and design parameters that are important for successful enhanced biological phosphorus removal (EBPR).

For wastewater treatment plants utilizing EBPR, specific conditions must exist for them to function properly and favors phosphorus-accumulating organisms (PAO).

A. Biochemical oxygen demand (BOD) or chemical oxygen demand (COD)/total phosphorus ratio
As discussed earlier, the influent BOD or COD to total phosphorus ratio is critical for PAOs to grow, function, and take up phosphorus from solution. The influent BOD or COD must be in a form that is readily available to PAOs, such as volatile fatty acids (VFA). A minimum BOD/total phosphorus ratio of 20:1 or a COD/total phosphorus ratio of 45:1 is needed for successful EBPR.

B. Sludge age and hydraulic retention time (HRT)
The contact time between the influent and the bacteria (HRT) in the anaerobic selector as well as the proper sludge age for the microbial biochemical reactions to take place in the biomass are critical for PAO growth, metabolism, and selection.

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

D. Internal recycle flows (sidestreams)
Internal recycle flows 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 enhanced biological phosphorus removal (EBPR).

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 increase the phosphorus content of biosolids. 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

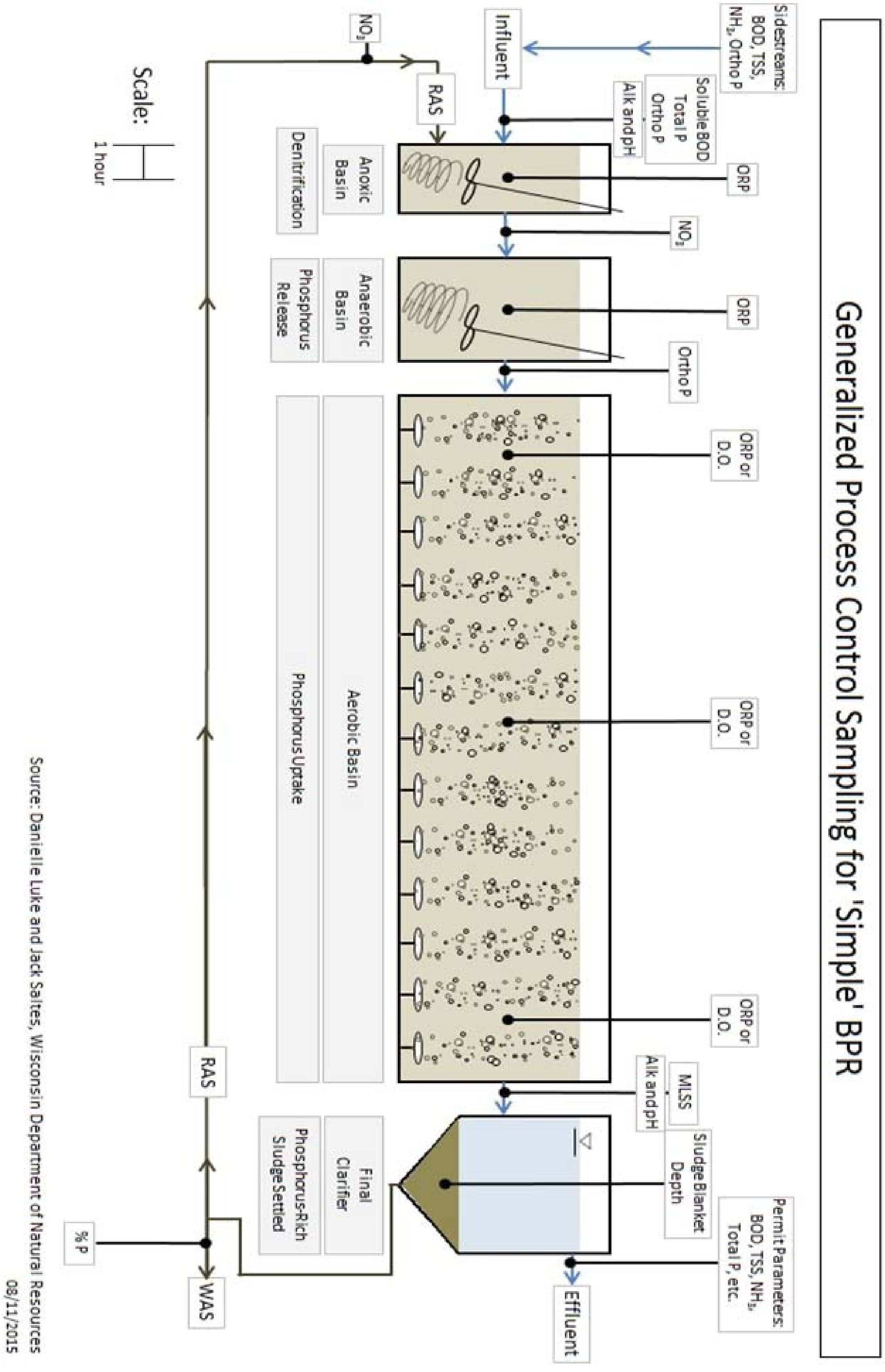
3.1.1 Define secondary release.

Secondary release is the release of phosphorus in an enhanced biological phosphorus removal (EBPR) system not associated with substrate (food) uptake. Secondary release is a release of phosphorus in the plant where it is not wanted.

Section 3.2 - Sampling and Testing

3.2.1 Show a generalized process control sampling for a simple biological phosphorus removal (BPR) plant.

Figure 3.2.1.1



Source: Danielle Luke and Jack Saltes, Wisconsin Department of Natural Resources
08/11/2015

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

A. Total phosphorus
B. Orthophosphate
C. Biochemical oxygen demand (BOD)
D. Soluble BOD
E. Nitrates
F. Chemical oxygen demand (COD)
G. Volatile fatty acids (VFA)
H. Percent phosphorus content in total suspended solids (TSS)

3.2.3 Describe the total phosphorus lab test, 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. The total phosphorus test uses acid digestion and is then determined by either colorimetric, spectrophotometric, or ion chromatographic methods.

The sampling locations include: influent, primary clarifier effluent, recycle streams (sidestreams), and effluent. 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 the plant’s discharge permit. It is important to know what the levels of phosphorus are entering the facility because high influent phosphorus loading could be the cause of high effluent phosphorus levels.

3.2.4 Decribe the orthophosphate lab test, 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 give quick results using colorimetric measurement. Operators can compare total phosphorus results to orthophosphate results and determine a multiplication factor which can be used to estimate a total phosphorus value from an orthophosphate result. 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 3 to 4 times higher than the influent. This tells the operator if a good phosphorus release is taking place in the anaerobic zone.

The sampling locations include: influent, primary clarifier effluent, anaerobic and aerobic zones, recycle streams, final clarifiers, and effluent. The orthophosphate test is quick and an easy way to estimate phosphorus levels and to monitor phosphorus release in the anaerobic selector.

3.2.5 Decribe the BOD5 lab test, its sampling locations, and the reason for sampling.

The BOD5 test measures the oxygen utilized during a 5-day incubation period at 20°C and is used to determine the organic strength of the wastewater. The BOD concentration entering an enhanced biological phosphorus removal (EBPR) 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 EBPR.

The BOD5 sampling locations include: influent and primary clarifier effluent. The BOD5 test is used to monitor the BOD to total phosphorus ratio.

3.2.6 Describe the soluble BOD5 lab test, its sampling locations, and reason for sampling.

Soluble BOD5 is a BOD5 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 phosphate-accumulating organisms (PAO) 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 EBPR process is dependent on having readily degradable food source or soluble BOD available to the PAOs.

The soluble BOD5 sampling locations include: influent and primary effluent. The soluble BOD5 test is run to have information on the amount of food (BOD) that is more readily available to the microorganisms, especially PAOs.

3.2.7 Describe the nitrate lab test, its sampling locations, and reason for sampling.

Nitrate 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, because if the EBPR process is to be successful, no nitrates can be present in the anaerobic zone. If the facility nitrifies, denitrifying will need to be done before the return activated sludge (RAS) enters the anaerobic zone. Sidestreams should also be tested for nitrates.

The nitrate test sampling locations include: RAS, anaerobic and aerobic zones, and any sidestreams. The reason for sampling is to monitor nitrates entering or already in the anaerobic zone.

3.2.8 Describe the COD test, 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 BOD5 test for process control because the results are available in about 3 hours rather than 5 days. The COD to phosphorus ratio for EBPR should be at least 45:1.

The COD test sampling locations include: influent and primary and final effluents and is used to monitor the COD to phosphorus ratio.

3.2.9 Describe the VFA test, its sampling locations, and reason for sampling.

VFAs provide the food that PAOs uptake in the anaerobic zone. Sufficient VFAs must be present when entering the anaerobic zone for successful EBPR. Testing for VFAs in the anaerobic selector influent can help determine if VFAs are a performance limiting factor. One reference states that 5 to 10 mg/L of VFAs are needed per mg/L of phosphorus to be removed (MOP 29, pg. 272). For the total VFAs as acetic acid test, Standard Methods 5560 C can be used. This method is good for process control and for VFA information.

Standard Methods 5560 C is a distillation lab procedure that provides VFA analysis for water soluble fatty acids up to 6 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 VFAs can be by gas chromatography, but this may be beyond what is needed for process control information.

The VFA test sampling location is from the influent entering an anaerobic zone and is used to determine whether VFAs are a limiting factor for EBPR.

3.2.10 Describe the percent phosphorus content in the TSS, its sampling locations, and reason for sampling.

A sample is filtered through a 0.45 µm 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 TSS of the sample and multiplying by 100 to get a percentage.

The sampling location for the percent phosphorus content in the TSS is from the waste activated sludge (WAS). 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.

3.2.11 Discuss inline monitoring of the biological phosphorus process using oxidation reduction potential (ORP) and dissolved oxygen (DO) meters.

While DO 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 DO meter.

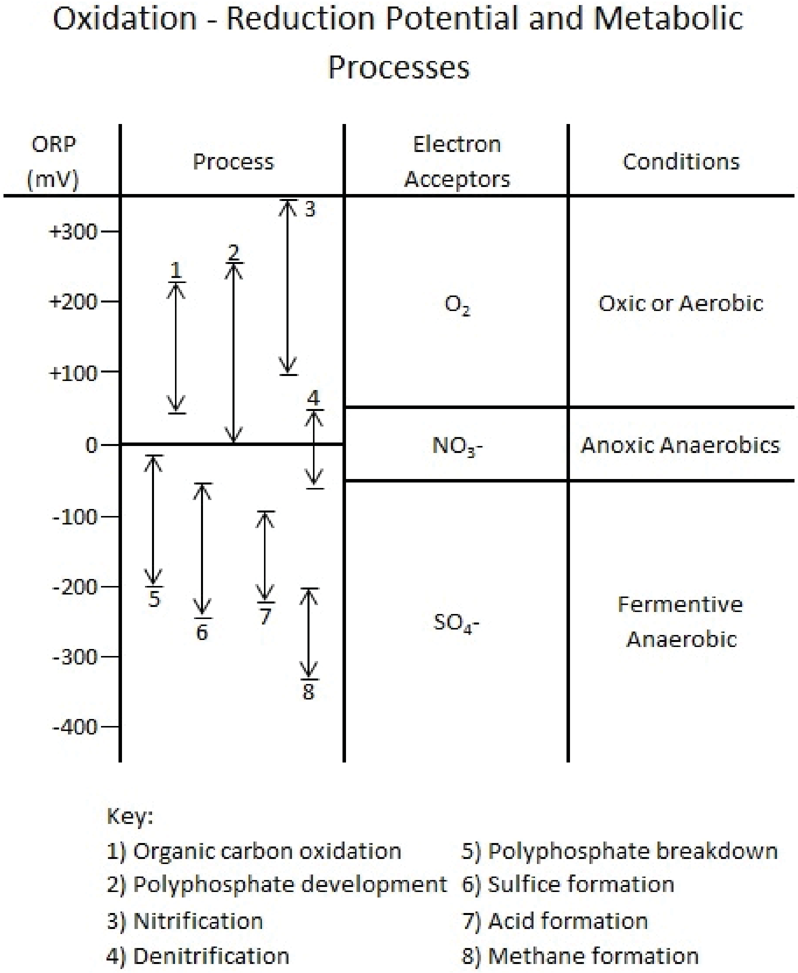
In wastewater, the ORP is the tendency of the solution to either gain or lose electrons. Oxidizing agents take on electrons while reducing agents give up electrons. Raw wastewater typically contains more reducing agents than oxidizing agents and in the biological treatment of wastewater bacteria, in 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 the figure below.

Graphic source: Gronsky, et al., 1992.

Figure 3.2.11.1


Oxidation - Reduction Potential and Metabolic Processes

Key:

1) Organic carbon oxidation	5) Polyphosphate breakdown
2) Polyphosphate development	6) Sulfice formation
3) Nitrification	7) Acid formation
4) Denitrification	8) Methane formation

Section 3.3 - Data Understanding and Interpretation

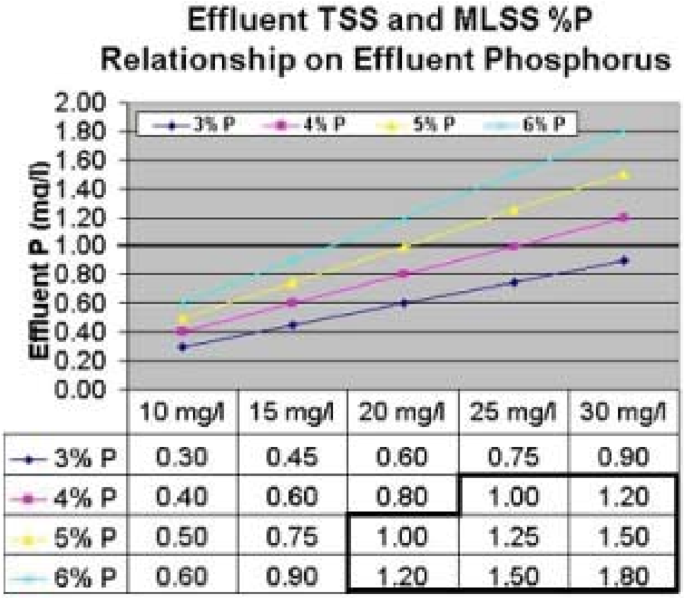
3.3.1 Discuss the fate of phosphorus as it passes through a treatment plant.

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 enhanced biological phosphorus removal (EBPR), the phosphorus-accumulating organisms (PAO) 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 Describe the significance of phosphorus content in the sludge as related to biological phosphorus efficiency and effluent phosphorus.

Sludge phosphorus content is defined as the percentage of phosphorus in cell mass and is expressed as phosphorus/volatile suspended solids (VSS)%. In a conventional activated sludge treatment process, the sludge phosphorus content is approximately 1.5% to 2.5%. In an EBPR system, the sludge phosphorus content is 3.0% to 6.0% or higher. The more efficient the EBPR system is, the higher the sludge phosphorus content will be. Phosphorus is removed from the treatment system by wasting sludge. Because the activated sludge phosphorus content is high in an EBPR plant, effluent TSS should be kept low. A small amount of TSS with high phosphorus content could contribute to a high total phosphorus concentration in the effluent.

Figure 3.3.2.1



	10 mg/l	15 mg/l	20 mg/l	25 mg/l	30 mg/l
3% P	0.30	0.45	0.60	0.75	0.90
4% P	0.40	0.60	0.80	1.00	1.20
5% P	0.50	0.75	1.00	1.25	1.50
6% P	0.60	0.90	1.20	1.50	1.80

3.3.3 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 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:

A. The retention time of the anaerobic selector of an EBPR process is too long

B. The retention time of settled sludge in the clarifier is too long

C. The retention time of the aerobic stage of an EBPR process is too long, causing cell lysis and phosphorus release

D. 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 - Sidestreams

3.4.1 Discuss sidestream treatment of phosphorus when using enhanced biological phosphorus removal (EBPR).

The idea of EBPR is to create conditions in secondary treatment that result in the microorganisms absorbing excess phosphorus. This phosphorus is removed from the flow when the activated sludge is wasted. If a sidestream is high in phosphorus, the sidestream can be treated. Metal salts can be added to these sidestreams to precipitate the phosphorus to avoid overloading the plant. If only the sidestream is treated chemically, biological phosphorus effluent limits still apply.

Section 3.5 - Corrective Actions

3.5.1 Discuss a control strategy for nitrates.

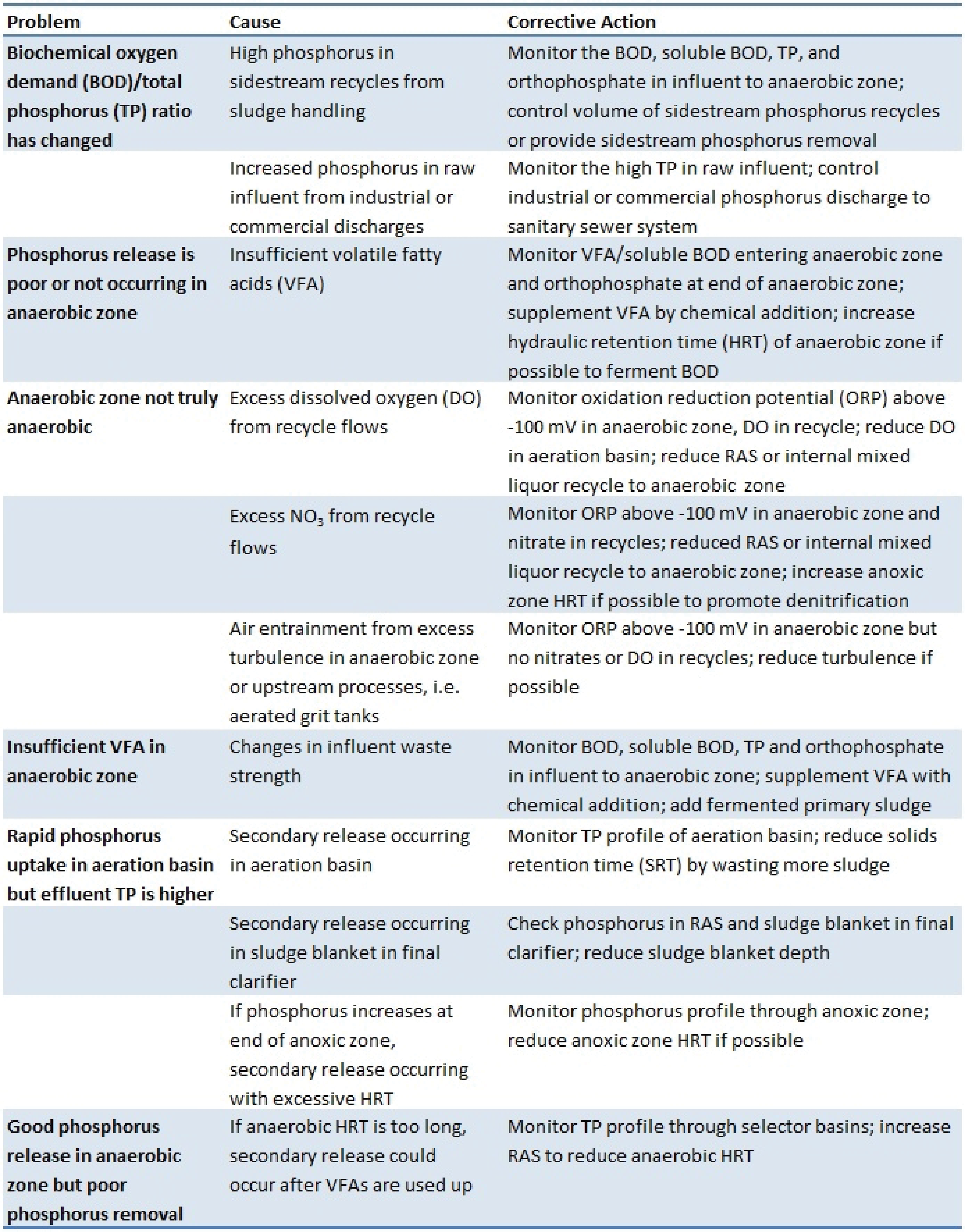
If a treatment plant is required to remove ammonia, the plant will be designed to nitrify. Many plants will nitrify, even if ammonia removal is not required, if a longer sludge age is used. Care must be taken not to introduce nitrates into the anaerobic zone with recycled activated sludge (RAS) or mixed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

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 sidestreams should be managed to limit the nitrates returned to the anaerobic zone.

An anoxic zone is often incorporated in enhanced biological phosphorus removal (EBPR) plants to promote denitrification.

3.5.2 Discuss corrective actions that can be taken when problems removing phosphorus biologically occur.

Figure 3.5.2.1



Problem	Cause	Corrective Action
Biochemical oxygen demand (BOD)/total phosphorus (TP) ratio has changed	High phosphorus in sidestream recycles from sludge handling	Monitor the BOD, soluble BOD, TP, and orthophosphate in influent to anaerobic zone; control volume of sidestream phosphorus recycles or provide sidestream phosphorus removal
	Increased phosphorus in raw influent from industrial or commercial discharges	Monitor the high TP in raw influent; control industrial or commercial phosphorus discharge to sanitary sewer system
Phosphorus release is poor or not occurring in anaerobic zone	Insufficient volatile fatty acids (VFA)	Monitor VFA/soluble BOD entering anaerobic zone and orthophosphate at end of anaerobic zone; supplement VFA by chemical addition; increase hydraulic retention time (HRT) of anaerobic zone if possible to ferment BOD
Anaerobic zone not truly anaerobic	Excess dissolved oxygen (DO) from recycle flows	Monitor oxidation reduction potential (ORP) above -100 mV in anaerobic zone, DO in recycle; reduce DO in aeration basin; reduce RAS or internal mixed liquor recycle to anaerobic zone
	Excess NO_3 from recycle flows	Monitor ORP above -100 mV in anaerobic zone and nitrate in recycles; reduced RAS or internal mixed liquor recycle to anaerobic zone; increase anoxic zone HRT if possible to promote denitrification
	Air entrainment from excess turbulence in anaerobic zone or upstream processes, i.e. aerated grit tanks	Monitor ORP above -100 mV in anaerobic zone but no nitrates or DO in recycles; reduce turbulence if possible
Insufficient VFA in anaerobic zone	Changes in influent waste strength	Monitor BOD, soluble BOD, TP and orthophosphate in influent to anaerobic zone; supplement VFA with chemical addition; add fermented primary sludge
Rapid phosphorus uptake in aeration basin but effluent TP is higher	Secondary release occurring in aeration basin	Monitor TP profile of aeration basin; reduce solids retention time (SRT) by wasting more sludge
	Secondary release occurring in sludge blanket in final clarifier	Check phosphorus in RAS and sludge blanket in final clarifier; reduce sludge blanket depth
	If phosphorus increases at end of anoxic zone, secondary release occurring with excessive HRT	Monitor phosphorus profile through anoxic zone; reduce anoxic zone HRT if possible
Good phosphorus release in anaerobic zone but poor phosphorus removal	If anaerobic HRT is too long, secondary release could occur after VFAs are used up	Monitor TP profile through selector basins; increase RAS to reduce anaerobic HRT

Chapter 4 - Safety

Section 4.1 - Safety

4.1.1 Discuss the potential safety hazards when operating an enhanced biological phosphorus removal (EBPR) system.

A. Falling into a basin
B. Slipping when conditions are wet or icy
C. Biohazards of wastewater
D. Sample preservation and analysis (strong acid)

4.1.2 Discuss the importance of floatation devices at a wastewater treatment plant.

Sampling from basins, channels, and other treatment processes puts an operator at risk of falling into the wastewater. Basins that are aerated can be the most dangerous because the aeration process makes it extremely difficult to stay afloat in waters saturated with high concentrations of air. For this reason, an operator should never extend beyond the protection of the guardrails. OSHA highly recommends ring buoys with at least 90 ft of line be provided and readily available for emergencies and strategically placed around all process basins. OSHA also recommends any operator working over or near water where a risk of drowning is present be provided with a life jacket or buoyant work vest.

Chapter 5 - Calculations

Section 5.1 - Calculations

5.1.1 Given data, determine the total phosphorus (TP) loading (lbs/day) into a treatment plant.

GIVEN:
[MGD = million gallons per day]
[gpd = gallons per day]

Influent flow = 0.240 MGD
Influent TP = 6 mg/L
Sludge storage tank decant flow = 10,000 gpd
Sludge storage tank decant TP = 48 mg/L
Belt press filtrate flow = 12,000 gpd
Belt press filtrate TP = 20 mg/L

FORMULAS AND SOLUTION:

Decant TP (lbs/day) = decant flow (MGD) × decant TP conc. (mg/L) × 8.34
= 0.010 MGD × 48 mg/L × 8.34
= 4.0 lbs of TP/day

Filtrate TP (lbs/day) = filtrate flow (MGD) × filtrate TP conc. (mg/L) × 8.34
= 0.012 MGD × 20 mg/L × 8.34
= 2.0 lbs of TP/day

TP from sidestreams (lbs/day) = decant TP (lbs/day) + filtrate TP (lbs/day)
= 4.0 lbs/day + 2.0 lbs/day
= 6.0 lbs/day

Influent TP (lbs/day) = influent flow (MGD) × influent TP conc. (mg/L) × 8.34
= 0.240 MGD × 6 mg/L × 8.34
= 12.0 lbs/day

TP loading (lbs/day) = influent TP (lbs/day) + TP from sidestreams (lbs/day)
= 12 lbs/day + 6 lbs/day
= 18 lbs of TP/day

5.1.2 Given data, calculate the phosphorus load (lbs/day) from the sidestream (decant from a sludge storage tank).

GIVEN:

Decant flow = 75,000 gpd
Decant phosphorus concentration = 35 mg/L

FORMULA AND SOLUTION:

TP load (lbs) = decant flow (MG) × phosphorus conc. (mg/L) × 8.34
= 0.075 MG × 35 mg/L × 8.34
= 22 lbs/day

5.1.3 Will the influent wastewater to a treatment plant be amenable to enhanced biological phosphorus removal (EBPR) if the influent biochemical oxygen demand (BOD) is 275 mg/L and the influent phosphorus is 12 mg/L? A ratio greater than 20:1 is needed.

GIVEN:

Influent BOD = 275 mg/L
Influent TP = 12 mg/L

FORMULA AND SOLUTION:

Influent BOD/TP ratio = influent BOD (mg/L) ÷ influent TP (mg/L)
= 275 mg/L ÷ 12 mg/L
= 23:1; Yes, this ratio indicates it will be amenable to EBPR

5.1.4 Determine the hydraulic retention time (HRT) (hrs) in an anaerobic selector.

GIVEN:

Influent flow = 1.15 MGD
Return activated sludge (RAS) flow = 0.600 MGD
Selector volume = 150,000 gals

FORMULA AND SOLUTION:

HRT (hrs) = (tank vol. (MG) ÷ [influent flow (MGD) + RAS flow (MGD)]) × 24 hrs/day

= (0.150 MG ÷ [1.15 MGD + 0.600 MGD]) × 24 hrs/day
= (0.150 MG ÷ 1.75 MGD) × 24 hrs/day
= 2.1 hrs

5.1.5 Determine the hydraulic retention time (HRT) (hrs) in an anaerobic selector.

GIVEN:

Influent flow = 1.25 MGD
Selector volume = 0.050 MG

FORMULA AND SOLUTION:

HRT (hrs) = (selector vol. (MG) ÷ influent flow (MGD)) × 24 hrs/day
= (0.050 MG ÷ 1.25 MGD) × 24 hrs/day
= 0.96 or 1 hr

5.1.6 Determine the sludge age (days) in an EBPR plant.

GIVEN:

Total volume of the anoxic, anaerobic, and aeration basins = 475,000 gals
Mixed liquor suspended solids (MLSS) = 2,200 mg/L
Wasting rate = 12,000 gpd
Wasted activated sludge (WAS) concentration = 4,000 mg/L

FORMULAS AND SOLUTION:

Solids in reactors (lbs) = total reactors' vol. (MG) × MLSS (mg/L) × 8.34
= 0.475 MG × 2,200 mg/L × 8.34
= 8,715 lbs of MLSS

Solids removed daily (lbs/day) = WAS rate (MGD) × WAS conc. (mg/L) × 8.34
= 0.012 MGD × 4,000 mg/L × 8.34
= 400 lbs of WAS/day

Sludge age (days) = solids in biological reactors (lbs) ÷ solids removed daily (lbs)
= 8,715 lbs of MLSS ÷ 400 lbs of WAS/day
= 22 days

5.1.7 Determine the sludge age (days) in an EBPR plant.

GIVEN:

Anaerobic selector volume = 45,000 gals
Anoxic selector volume = 55,000 gals
Aeration basis volume = 500,000 gals
MLSS = 3,400 mg/L
Wasting rate = 20,000 gpd

WAS concentration = 5,000 mg/L

FORMULAS AND SOLUTION:

Solids in reactors (lbs) = tank vol. (MG) × MLSS (mg/L) × 8.34
= (0.045 MG + 0.055 MG + 0.500 MG) × 3,400 mg/L × 8.34
= 17,014 lbs

Solids removed (lbs/day) = WAS rate (MGD) × WAS concentration (mg/L) × 8.34
= 0.020 MGD × 5,000 mg/L × 8.34
= 834 lbs of WAS/day

Sludge age (days) = solids in reactors (lbs) ÷ solids removed (lbs/day)
= 17,014 lbs ÷ 834 lbs/day
= 20 days

Part 2 - Chemical Removal

Chapter 6 - Theory and Principles

Section 6.1 - Definitions

6.1.1 Define alkalinity.

Alkalinity is the ability of wastewater to neutralize acids caused by water's carbonate, bicarbonate, and hydroxide content. It is a measure of how much acid must be added to lower the pH to 4.5. Wastewater that has low alkalinity will see the pH drop more easily than a high alkaline wastewater when acidic metal salts are added for phosphorus removal. Alkalinity is expressed in milligrams per liter (mg/L) of equivalent calcium carbonate.

6.1.2 Define chemical precipitation.

Chemical 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 be removed with the sludge. Several different metal salts are commonly used to chemically precipitate phosphorus.

6.1.3 Define coagulation.

Coagulation is 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.

6.1.4 Define crystallization.

Crystallization is the formation of solids from solution due to changes in temperature and concentration.

6.1.5 Define eutrophication.

Eutrophication is the excessive growth of plant and algae in receiving waters due to dissolved nutrients and their decomposition.

6.1.6 Define flocculation.

Flocculation is 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.

6.1.7 Define metal salt.

Metal salt is a term used to describe iron, aluminum, and calcium compounds used in chemical phosphorus removal.

6.1.8 Define mole.

The molecular weight of a substance, usually expressd in grams.

Section 6.2 - Origins and 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 (DO) 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 and test each load of hauled wastes brought in to the treatment plant. The cost of phosphorus removal should be considered in setting fees for treating hauled wastes.

Section 6.3 - Chemicals and Chemical Reactions

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

A. Ferric chloride
B. Ferrous chloride
C. Ferrous sulfate
D. Aluminum sulfate (alum)

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

A. Ferric chloride (FeCl3)
   1. Acidic (may lower pH) and alkalinity
   2. Very corrosive
   3. Fume producing
   4. Supplied as 33% to 36% solution (11% to 13% iron)
   5. Several grades available
   6. Stains concrete and other materials
   7. Can affect ultraviolet (UV) disinfection
   8. May affect effluent chloride

B. Ferrous chloride (FeCl2)
   1. Acidic (may lower pH) and alkalinity
   2. Very corrosive
   3. Fume producing
   4. Supplied as 18% to 28% solution (8% to 13% iron)
   5. Stains concrete and other materials
   6. May affect effluent chloride
   7. May affect UV disinfection
   8. Potential impurities

C. Ferrous sulfate (FeSO4)
  1. Acidic (may lower pH) and alkalinity
  2. Very corrosive
  3. Fume producing
  4. Supplied as 23% to 25% solution (5% to 7% iron)
  5. Stains concrete and other materials
  6. Should be stored in indoor heated space
  7. May affect UV disinfection
  8. Potential impurities

D. Alum (Al2(SO4)3)
  1. Acidic (may lower pH) and alkalinity
  2. Moderately corrosive
  3. 49% aluminum sulfate (8% to 9% aluminum) in liquid form
  4. Also available in dry form (powder); must be mixed with water before use
  5. Very temperature sensitive in liquid form (must be kept above freezing)
  6. Clear, light green, or yellow liquid

6.3.3 Describe the precipitates that form when metal salts are added to wastewater.

When metal ions, iron or aluminum, are added to wastewater two primary precipitates form: an insoluble metal phosphate and an insoluble metal hydroxide. For a given metal, the formation of these precipitates is governed by the wastewater alkalinity and soluble orthophosphate concentration in the wastewater, as well as their equilibrium solubility at a given pH.

6.3.4 Describe the use of polymers in phosphorus removal.

Polymers can be used as a supplement to enhance phosphorus removal by improving coagulation and settling. Polymers are usually added prior to final clarifiers. The better the settling, the less solids and phosphorus there will be in the final effluent.

6.3.5 Describe crystallization characteristics of phosphorus removing chemicals.

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

A. Ferric chloride (FeCl3)
  1. - 42ºF at 35% solution
  2. 20ºF at 42% solution

B. Ferrous chloride (FeCl2)
  1. 28ºF at 25% Solution
  2. 42ºF at 35% Solution

C. Ferrous sulfate (FeSO4)
  1. 42ºF at 25% Solution

D. Alum (Al2(SO4)3)

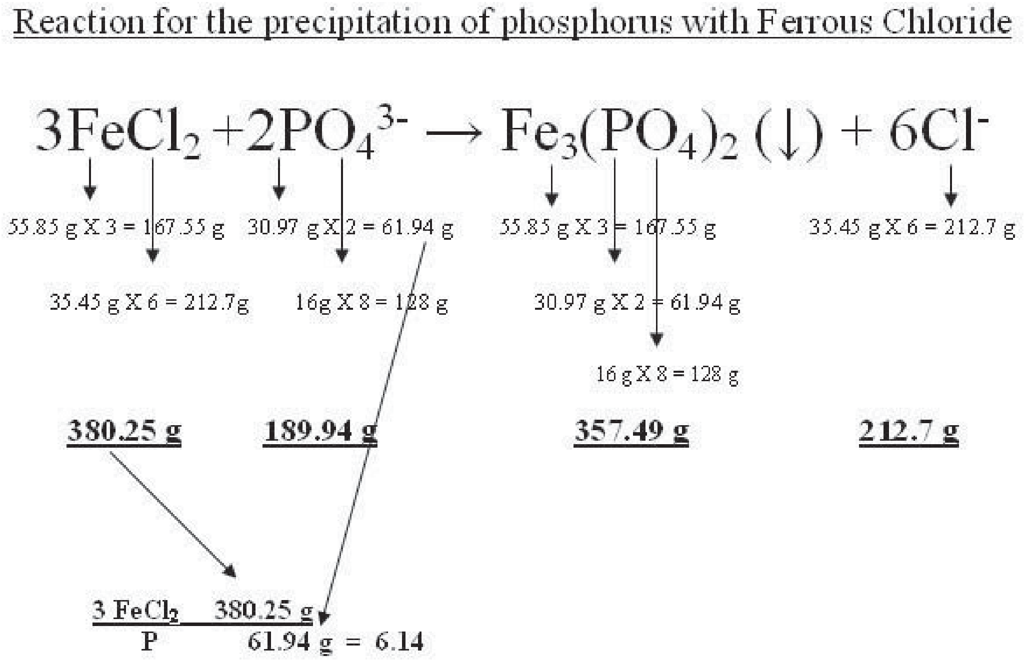
1. 32ºF at 8% aluminum sulfate

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

6.3.6 Describe the chemical reaction of the ferrous chloride with phosphorus.

Graphic source: Jeremy Cramer, Stevens Point

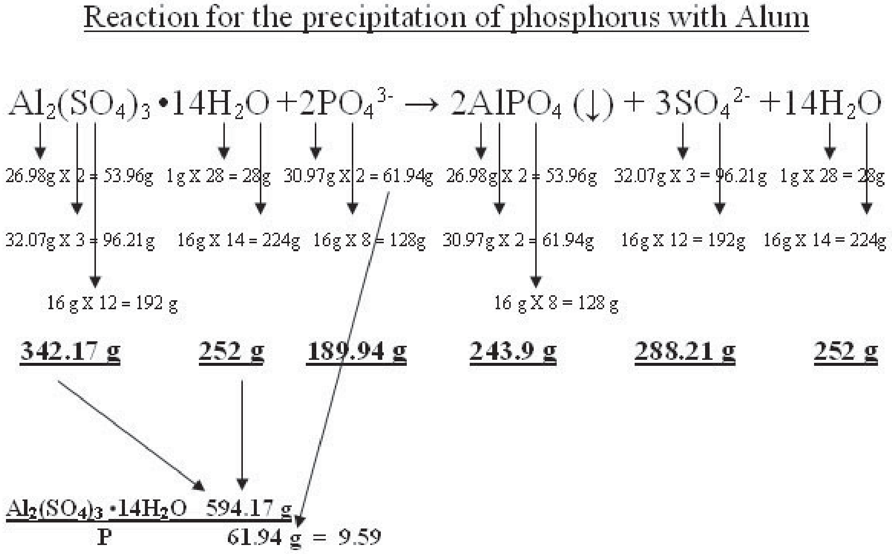
Figure 6.3.6.1



6.3.7 Describe the chemical reaction of the alum with phosphorus.

Graphic source: Jeremy Cramer, Stevens Point

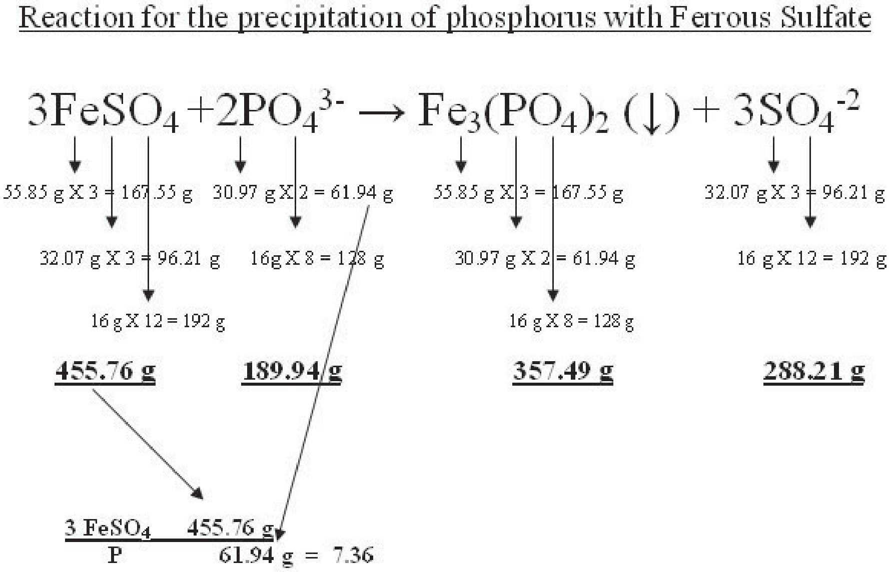
Figure 6.3.7.1



6.3.8 Describe the chemical reaction of the ferrous sulfate with phosphorus.

Graphic source: Jeremy Cramer, Stevens Point

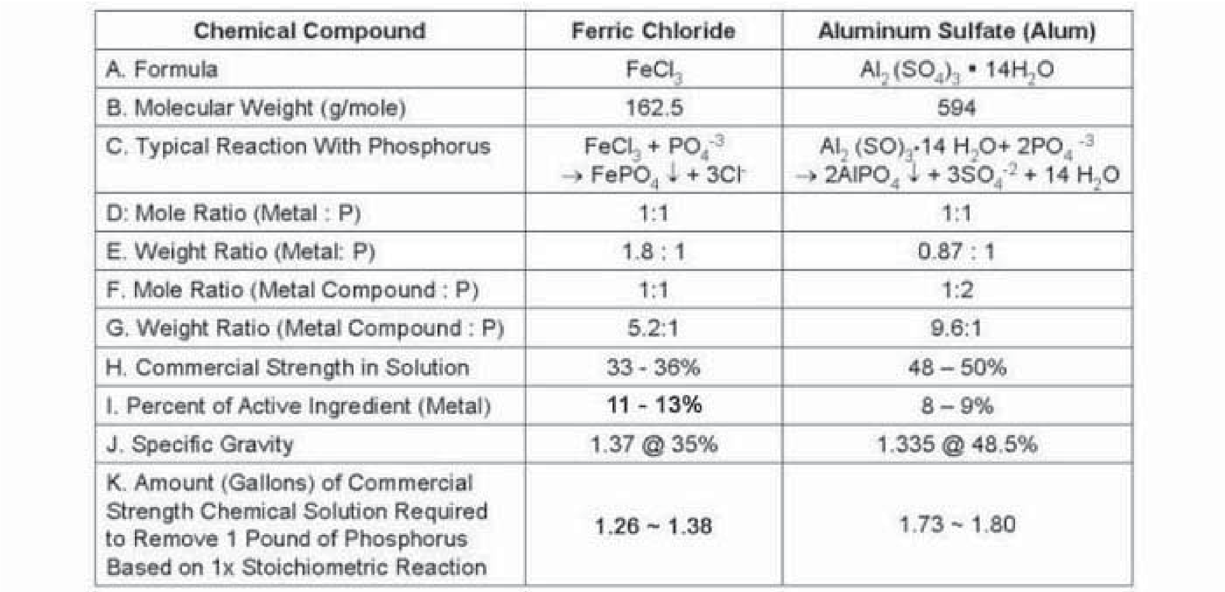
Figure 6.3.8.1



6.3.9 Summarize the information of the chemicals (metal salts) used for phosphorus removal.

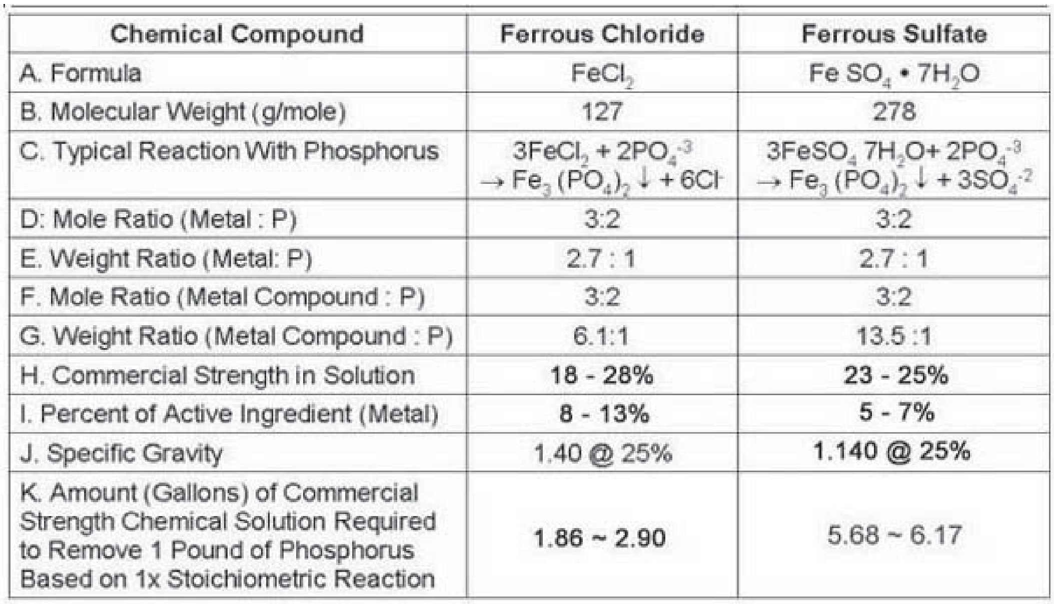
Graphic source: Jenchie Wang, Symbiont

Figure 6.3.9.1



Chemical Compound	Ferric Chloride	Aluminum Sulfate (Alum)
A. Formula	$FeCl_3$	$Al_2(SO_4)_3 \cdot 14H_2O$
B. Molecular Weight (g/mole)	162.5	594
C. Typical Reaction With Phosphorus	$FeCl_3 + PO_4^{-3}$ $\rightarrow FePO_4 \downarrow + 3Cl^-$	$Al_2(SO)_3 \cdot 14 H_2O + 2PO_4^{-3}$ $\rightarrow 2AlPO_4 \downarrow + 3SO_4^{-2} + 14 H_2O$
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	$FeCl_2$	$Fe\,SO_4 \cdot 7H_2O$
B. Molecular Weight (g/mole)	127	278
C. Typical Reaction With Phosphorus	$3FeCl_2 + 2PO_4^{-3}$ $\rightarrow Fe_3(PO_4)_2 \downarrow + 6Cl^-$	$3FeSO_4\,7H_2O + 2PO_4^{-3}$ $\rightarrow Fe_3(PO_4)_2 \downarrow + 3SO_4^{-2}$
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

6.3.10 Discuss the effect of wastewater pH on phosphorus removal chemical feed requirements.

Each phosphorus removal chemical (metal salt) has an optimum pH range for precipitating out the phosphorus as a metal phosphate. Iron phosphate [FePO4] and alum [AlPO4] are least soluble at a pH of 6.8 to 7.0, thus precipitate out best at this pH range. Wastewater pH levels outside of this optimum range will require more chemical to achieve the same removal efficiency. While not all wastewaters are at a pH of 6.8 to 7.0, metal phosphates still precipitate out well in the pH range of most wastewaters of 6.0 to 8.5.

6.3.11 Discuss the effects of influent wastewater with high sulfides on phosphorus removal using iron salts.

Sulfide will react with iron forming a black precipitate. High sulfide wastewater will require higher dosages of iron salts.

Sources of sulfides include hauled and certain industrial wastes and collection systems with long detention times.

6.3.12 Describe how the metal salt dose changes to meet very low effluent phosphorus limits.

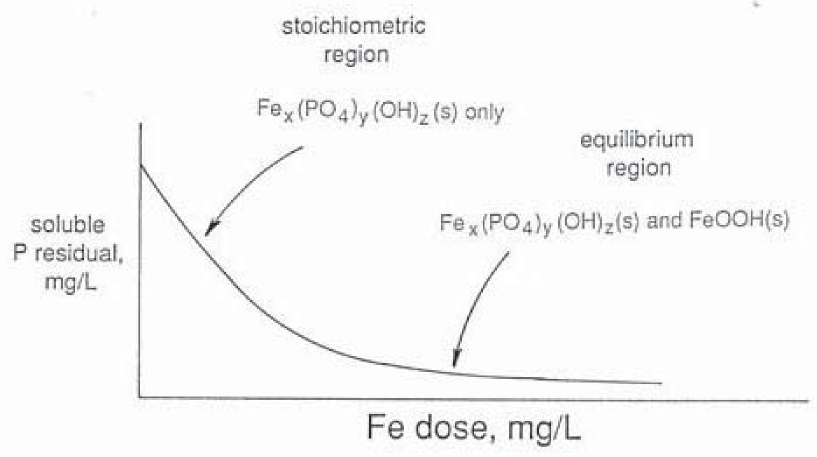
Reaching very low effluent phosphorus concentrations requires increasing amounts of metal salt because of the competition between phosphate and hydroxide precipitation.

Using either aluminum or iron salts, a graph of metal dose versus residual dissolved phosphorus can be drawn that illustrates this relationship (see figure 6.3.12.1).

At a given pH and alkalinity, the dissolved orthophosphate concentration in the wastewater will determine whether metal phosphates or metal hydroxides are formed. As the dissolved phosphorus concentration (effluent phosphorus) decreases, more metal hydroxides will be formed.

To achieve low effluent phosphorus limits, increasingly larger doses of metal salts are required to remove additional phosphorus. Eventually, chemical equilibrium will be reached with no further reduction in phosphorus.

Figure 6.3.12.1



Typical Fe dose versus soluble P residual curve.

Section 6.4 - Perfomance 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.

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 (WAS), therefore solids carryover from overloaded clarifiers will increase effluent phosphorus.

Chapter 7 - Operation and Maintenance

Section 7.1 - Definitions

7.1.1 Define vivianite.

Vivianite, a hydrated iron phosphate ($Fe3(PO4)2 \bullet 8(H^{2}0)$), is a hard crystal that can form in wastewater treatment plant piping and valving when iron salts are added in excess for chemical phosphorus removal.

Section 7.2 - Methods

7.2.1 List the methods used to determine the amount of solution removed from chemical storage tanks.

A. Ultrasonic sensors
B. Sight glasses
C. Scales
D. 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.

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

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

A. Prior to primary clarification
  1. Advantages
    a. Metal salt addition upstream of primary clarifiers enhances suspended solids and biochemical oxygen demand (BOD) removal. This reduces loading to the aeration basin
    b. Odor control (especially iron salts)
    c. Convenience and mixing capability
    d. Iron compounds may help balance nutrients in anaerobic digester
    e. May reduce struvite formation

  2. Disadvantages
    a. Greater chemical usage
    b. May require additional chemical addition downstream
    c. May result in higher biosolids production
    d. Could affect nutrient ratio and pH for biological treatment
    e. 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)
  1. Advantages
    a. Good mixing in aerated basins or lagoons
    b. Fe^{+2} is oxidized to Fe^{+3} thus improving reaction with phosphate ($PO4^{-3}$)
    c. Orthophosphates are readily available
    d. Convenience

  2. Disadvantages
    a. Not recommended for attached growth systems
    b. Could affect pH, alkalinity, and nutrient ratio
    c. Not recommended for unmixed ponds and lagoons
    d. Iron discoloration of structures and equipment

C. Prior to final clarification
  1. Advantages
    a. Efficient and high level of removal because most phosphorus is the orthophosphate form
    b. Enhances final settling
    c. Less interfering or competing reactions
    d. Cost effectiveness

  2. Disadvantages

a. Inadequate mixing

7.2.3 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.

7.2.4 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.

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

For the continuous dosing of metal salts for remove phosphorus, add to the beginning of the last pond or lagoon where the precipitation reaction and settling can occur. The chemical should be added where good chemical mixing 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.

7.2.6 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 the chemical in a gridwork pattern across the entire pond surface. The floc that forms is allowed to settle for 24 to 48 hours and a sample of the treated pond is taken and tested 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 7.3 - Equipment

7.3.1 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 for chemical storage and usage

7.3.2 Describe the function and the most probable location in a phosphorus removal system of each equipment part.

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 to 25 psi over the back pressure valve setting. If the discharge pressure increases to over the pressure relief valve setting, caused by a blockage of the discharge line, the relief valve will open and release the 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 dampener
The pulsation dampener is part of the chemical-metering pump discharge line. The pulsation dampener acts as a shock absorber on the discharge line. The dampener reduces the discharge pressure surge on the discharge line during the discharge stroke of the chemical-metering pump.

F. Backflow preventer
The backflow preventer is a device installed on a water supply line that will prevent backflow of water or chemical back into the water supply system.

7.3.3 Discuss how chemical metering pumps can be controlled to feed chemical.

A. Manually
B. Automatically
    1. Flow
    2. Time
    3. Residual

7.3.4 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 7.4 - Handling and Storage

7.4.1 List the materials and conditions for the storage and feeding of phosphorus removal chemicals.

A. Iron salts
Ferric chloride, ferric sulfate, and ferrous chloride 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 (alum) should be stored in tanks made of 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.

7.4.2 Discuss ways to control corrosion from phosphorus removal chemicals.

A. Vent storage tanks to the outside of the building, 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

7.4.3 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, flushed with water, and the water removed before changing to another chemical. The operator must make sure 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.

Section 7.5 - Preventive Maintenance

7.5.1 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 any problems as soon as possible

B. Check the equipment for corrosion from chemical fumes; locate the source of fumes and repair or replace corroded parts, if necessary

C. Check for developing line blockage by monitoring the chemical metering pump discharge pressure; consult with chemical supplier

D. Confirm that the heating and ventilation systems are working properly and repair if necessary

7.5.2 List the preventive maintenance procedures for chemical feed pumps.

Operators should always read the manufacturer's O&M manual and follow the recommendations.

A. Check and change the oil in the gear case as suggested in the manufacturer’s 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 the 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 the pump tubing as recommended by manufacturer

Section 7.6 - Biosolids Issues

7.6.1 Discuss how much more biosolids could be expected to be produced when 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% to 25%.

7.6.2 Discuss the buildup of sludge in lagoons and ponds using chemicals for phosphorus removal.

Solids will accumulate in the pond where precipitates form and settle. The amount of chemical sludge produced is 7.5 mg chemical sludge per mg phosphorus removed for aluminum sulfate (alum), and 10 mg 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 and Testing

8.1.1 Describe how an operator or municipality could identify the 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
Determines the amount of phosphorus entering the plant

B. Sidestreams
Identifies internal sources of phosphorus

C. Effluent
Determines 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 testing 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 less than 2.0, cooled to 6°C or less, but not frozen, and can then be stored up to 28 days.

8.1.5 Describe jar testing.

Jar testing is a laboratory procedure used to simulate the results of using different chemical feed dosages. This procedure is used to determine the best chemical and dose rate required to achieve a water quality goal. Samples of the wastewater to be treated are placed in jars and varying amounts of the chemical are added to each of the jars and mixed. The lowest dose of the chemical that provides a satisfactory result of the dosage should be used to treat the water.

Section 8.2 - Process Understanding and 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 (H2PO4, HPO4, and PO4). 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 of a dose of metal salt can result in variable effluent phosphorus concentrations as well as violations of permit limits. Too high of a dose can result in wasted chemical, increased chemical costs, biological (pH and alkalinity) problems, and plugging problems in piping and valves.

8.2.3 Discuss the significance of the forms of phosphorus in wastewater.

Total phosphorus consists of soluble and particulate phosphorus. Metal salts primarily function to remove soluble phosphorus, which is measured as orthophosphate. The effluent total suspended solids (TSS) 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 Discuss the effect the addition of acidic metal salts can have on wastewater alkalinity and pH.

Both aluminum sulfate (alum) and iron metals salts are acidic and will reduce alkalinity and pH. In low alkalinity wastewater, the addition of metal salts could impair biological treatment, particularly nitrification, by consuming alkalinity. Care should be taken not to overdose metal salts. Adding metal salts before the final clarifiers rather than ahead of the biological reactor may mitigate the impact on the biological treatment.

8.2.6 Describe the effect algae can have on effluent suspended solids and phosphorus being discharged from a pond or 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 when using a metal salt to precipitate out phosphorus that excess algae is not discharged. This will help ensure meeting effluent limits.

Section 8.3 - Sidestreams

8.3.1 List common sidestreams within a treatment plant.

The most common recycle streams (or sidestreams) are from:

A. Thickening and dewatering process
  1. Gravity belt thickening filtrate
  2. Centrifuge centrate
  3. Gravity thickening supernatant
  4 Dissolved air filtration (DAF) subnatant
  5. Rotary drum thickening filtrate
  6. Belt filter press filtrate
  7. Sludge drying bed under drain
  8. Plate and frame filtrate
  9. Reed bed filtrate

B. Stabilization and storage
  1. Aerobic digester decant
  2. Anaerobic digestion supernatant
  3. Biosolids storage decant
  4. Effluent sand filter backwash

8.3.2 Discuss the possible impact of a sidestream high in suspended solids.

Sidestreams or recycle streams usually come from solids handling, treatment, or dewatering processes, such as decanting digesters or sludge storage tanks. These sidestreams could be problematic if the decant or filtrate is high in suspended solids. The suspended solids could contain large amounts of phosphorus, reintroducing both the solids and phosphorus back into the treatment process. The amount of phosphorus being recycled back through the treatment processes via high suspended solids could be significant. Old sludge solids may also be harder to settle, thus, if carried out in the effluent, could result in elevated suspended solids, biochemical oxygen demand (BOD), and phosphorus. Solids processing should be operated to minimize the amount of suspended solids in the sidestreams.

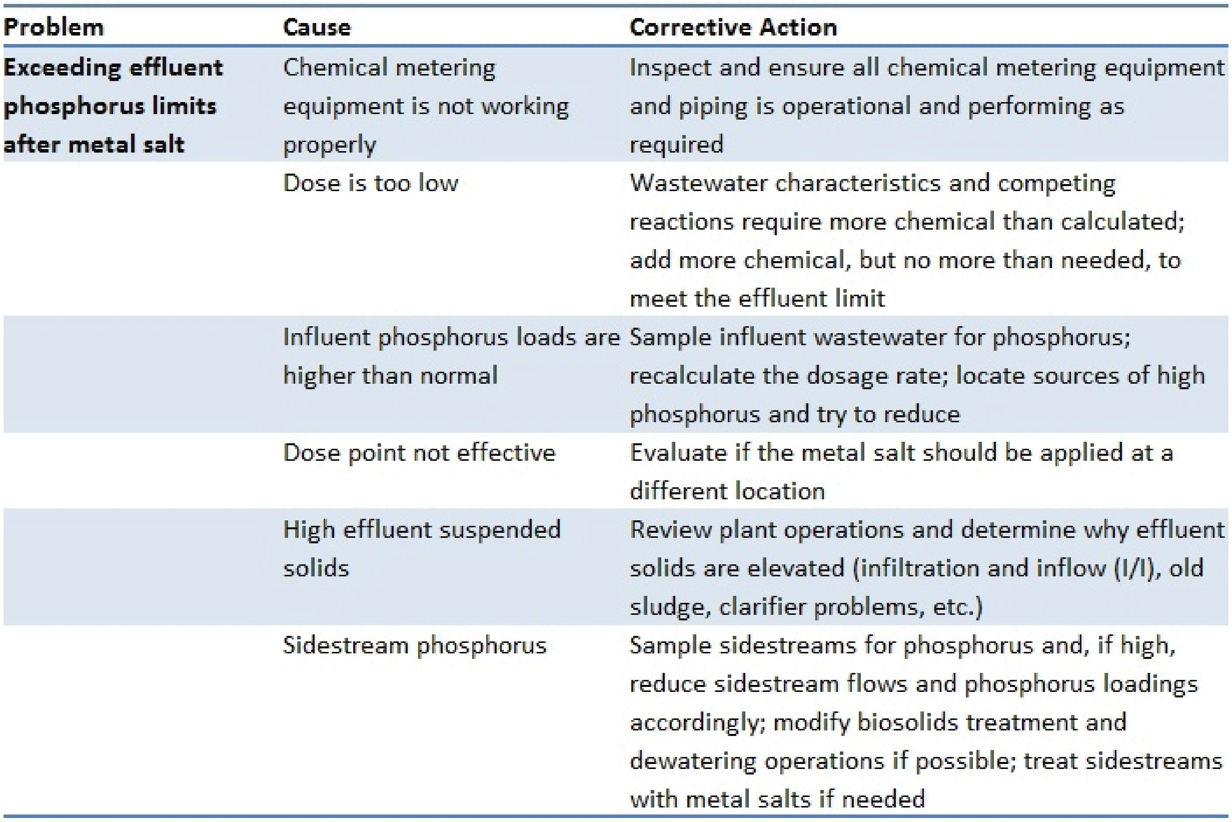
Section 8.4 - Corrective Actions

8.4.1 Discuss the problems associated with overfeeding of iron salts to wastewater.

A. Impedance of ultraviolet (UV) light transmittance
B. Plugging of seal water lines, if using effluent reuse
C. Plugging of air compressor cooling lines, if using effluent reuse
D. Formation of vivianite
E. Decreased pH and alkalinity
F. Excess chemical cost

8.4.2 State the possible causes and corrections for exceeding effluent phosphorus limits after metal salt addition.

Figure 8.4.2.1



Problem	Cause	Corrective Action
Exceeding effluent phosphorus limits after metal salt	Chemical metering equipment is not working properly	Inspect and ensure all chemical metering equipment and piping is operational and performing as required
	Dose is too low	Wastewater characteristics and competing reactions require more chemical than calculated; add more chemical, but no more than needed, to meet the effluent limit
	Influent phosphorus loads are higher than normal	Sample influent wastewater for phosphorus; recalculate the dosage rate; locate sources of high phosphorus and try to reduce
	Dose point not effective	Evaluate if the metal salt should be applied at a different location
	High effluent suspended solids	Review plant operations and determine why effluent solids are elevated (infiltration and inflow (I/I), old sludge, clarifier problems, etc.)
	Sidestream phosphorus	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 and Regulations

Section 9.1 - Regulations and Procedures

9.1.1 Discuss how phosphorus effluent limits are established for a wastewater treatment plant.

Wisconsin Administrative Code NR 217: Effluent Standards and Limitations set forth the requirements for setting effluent phosphorus limits. A water quality based effluent limitation for phosphorus will be included in a Wisconsin Pollutant Discharge Elimination System (WPDES) permit whenever the discharge or discharges from a point source contains phosphorus at concentrations or loadings which will cause, has the reasonable potential to cause or contribute to, an exceedance of the water quality standards in either the receiving water or downstream waters. Final effluent phosphorus limits can be incorporated into a WPDES permit as either a numerical concentration limit calculated under section 217.13 or as a mass limit from an Environmental Protection Agency (EPA) approved Total Maximum Daily Load (TMDL). Compliance with final effluent phosphorus limits can be achieved using a variety of options including: a treatment plant upgrade, Water Quality Trading or Adaptive Management.

9.1.2 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. Safety Data Sheets (SDS) are required to be kept onsite and available. Contact the Department of Natural Resources in event of a spill.

9.1.3 Discuss the reporting requirements for phosphorus removal chemicals under Federal, State, and Local laws.

In order to comply with Sections 311 and 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 Wisconsin Administrative Code, the Wisconsin State Emergency Response Board requires that all facilities having a hazardous chemical with SDS 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:

A. State Emergency Response Commission
B. Local Emergency Planning Committee
C. Local Fire Department

The report shall include the following information:

A. Chemical and common name of the chemical
B. Estimate of maximum amount of chemical at the facility in the preceding year
C. Estimate of the average daily amount of chemical at the facility in the preceding year
D. Description of the manner of storage
E. Location of the stored chemical at the facility

9.1.4 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 and uncoupling fill lines, place containment pails under potential leak points. Inspect and maintain fill lines and valves. Inspect storage tank and hardware for integrity.

Provide onsite containment equipment such as absorbent boom, sandbags, etc., and seal the yard and storm drains to prevent offsite loss of chemical. Pay attention to what is being done.

9.1.5 Discuss the proper procedure for entering a chemical storage tank.

All confined space procedures should be followed. Personal protective equipment (PPE) should be used. All tools and equipment used should be non-sparking/explosion proof. This type of work is often contracted to a specialty company.

Follow the plant's Safety Management Plan!

Section 9.2 - Equipment

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

The operator should wear personal protective equipment (PPE) 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 an uncontrollable release of chlorine gas.

B. Aluminum sulfate (alum) and sodium hypochlorite
The mixing of alum and sodium hypochlorite will cause an uncontrollable release of chlorine gas.

C. Ferric chloride and alum
The mixing of ferric chloride and alum will cause an exothermic reaction (releases heat) and a release of acidic 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 alum 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, and polymers when wet can be very slippery.

Chapter 10 - Calculations

Section 10.1 - Calculations

10.1.1 Given data, calculate the phosphorus loading to a plant (lbs/day).

GIVEN:
[MGD = million gallons per day]

Influent Flow = 2.7 MGD
Influent total phosphorus (TP) = 6.9 mg/L

FORMULA AND SOLUTION:

Phosphorus loading (lbs/day) = influent flow (MGD) × influent TP (mg/L) × 8.34
= 2.7 MGD × 6.9 mg/L × 8.34

= 155 lbs/day

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

GIVEN:

Influent flow = 2.0 MGD
Influent TP = 8.0 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 AND SOLUTION:

A. Determine the amount of influent phosphorus to remove
TP to remove (lbs) = influent flow (MGD) × TP conc. (mg/L) × 8.34
= 2.0 MGD × 8.0 mg/L × 8.34
= 133 lbs of phosphorus

B. Determine the metal salt in a solution (lbs/gal) knowing the specific gravity
Metal salt (lbs/gal) = specific gravity × 8.34
= 1.40 × 8.34
= 11.68 lbs of metal salt/gal

C. Determine the actual metal in a metal salt solution (lbs/gal) with a certain percent metal content
Metal in solution (lbs/gal) = metal salt (lbs/gal) × % metal
= 11.68 lbs × 0.125
= 1.5 lbs of metal/gal

D. Look up removal ratio for the metal salt being used

E. Determine the metal needed (lbs) to remove the incoming phosphorus (lbs)
Metal (lbs/day) to add to remove TP (lbs) = removal ratio × influent TP (lbs)
= 1.8 × 133 lbs TP
= 239 lbs/day of metal to add

F. Determine the metal salt solution to add (gpd) with a certain metal (%) content to add
Metal salt solution to add (gals) = metal to add (lbs) ÷ metal (lbs/gal)
= 239 lbs ÷ 1.5 lbs/gal
= 159 gpd of metal salt solution

10.1.3 The DNR NR 101 Wastewater Fee Program assesses an annual fee for the amount of phosphorus discharged (lbs/year). The rate for phosphorus is \$0.34 per pound discharged multiplied by an adjustment factor of 2.451. Given a total annual amount of phosphorus discharged, calculate the NR 101 wastewater fee.

GIVEN:

TP discharged = 6,950 lbs
Rate = \$0.34/lb
Adjustment factor = 2.451

FORMULA AND SOLUTION:

Amount due = TP discharged (lbs) × rate (\$) × adjustment factor
= 6,950 lbs × \$0.34/lb × 2.451
= \$5,792

10.1.4 Given data, calculate the phosphorus loading (lbs) from a sidestream.

GIVEN:

Sidestream flow = 60,000 gpd
TP concentration = 25 mg/L

FORMULA AND SOLUTION:

Sidestream TP (lbs) = sidestream flow (MG) × TP conc. (mg/L) × 8.34
= 0.060 MG × 25 mg/L × 8.34
= 12.5 lbs of TP/day

10.1.5 Given wastewater treatment plant and sidestream phosphorus loading information, calculate an acceptable sidestream flow rate (gpd).

GIVEN:

Design phosphorus loading = 15 lbs/day
Sidestream TP concentration = 10 mg/L
Recommended sidestream TP loading = No more than 5% of design loading

FORMULA AND SOLUTION:

Acceptable sidestream flowrate (gpd) = [design TP (lbs) × allowable for sidestream (%)] ÷ [(sidestream TP conc. (mg/L) × 8.34]
= (15 lbs/day × 0.05) ÷ (10 mg/L × 8.34)
= 0.009 MGD
= 9,000 gpd

10.1.6 Given the costs associated with chemical phosphorus removal, calculate the cost per pound of phosphorus removed.

GIVEN:

Average influent TP = 12 mg/L
Average influent flow = 0.650 MGD
Chemical cost per year = $4,400
Chemical feed O&M cost per year = $600
Sludge handling cost per year = $975

FORMULA AND SOLUTION:

TP removed ($/lb) = (chem. cost + O&M cost + sludge handling cost) ÷ TP removed (lbs/yr)
= ($4,400 + $600 + $975) ÷ (0.650 MGD × 12 mg/L × 8.34 × 365 days/yr)
= $5,975 ÷ 23,744 lbs of TP
= $0.25/lb of TP removed

References and Resources

1. **UW WATER LIBRARY**

   Most of the resources listed on this page can be borrowed through the UW Water Library as part of a partnership between the UW Water Library, the Wisconsin Wastewater Operator Association (WWOA), Central States Water Environmental Association (CSWEA), and the Wisconsin Department of Natural Resources. Instructions for borrowing materials from the UW Water Library can be found by visiting the website provided below, clicking on 'WISCONSIN RESIDENTS', and then clicking on 'HOW TO BORROW MATERIALS'.

   www.aqua.wisc.edu/waterlibrary

2. **OPERATION OF MUNICIPAL WASTEWATER TREATMENT PLANTS**

   Water Environmental Federation (WEF). (2008). Operation of Municipal Wastewater Treatment Plants: Manual of Practice No. 11 (6th ed., Vols. I, II, III). New York, New York: McGraw-Hill.

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   Office of Water Programs, California State University, Sacramento. (2008). Operation of Wastewater Treatment Plants (7th ed.). Sacramento, CA: University Enterprises, Inc., California State University.

   www.owp.csus.edu

4. **BIOLOGICAL NUTRIENT REMOVAL (BNR) OPERATION IN WASTEWATER TREATMENT PLANTS**

   Water Environment Federation (WEF). (2005). Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants (Vol. Manual of Practice No. 29). New York, NY: McGraw-Hill.

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   US Environmental Protection Agency (EPA) Technology Transfer. (1987). Phosphorus Removal Design Manual. Cincinnati, OH: Center for Environmental Research Information.

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7. **OPTIMIZING BPR PLANT OPERATIONS FOR ACHIEVING SUSTAINABLE LOW EFFLUENT PHOSPHORUS**

   Barnard, J. L., & Steichen, M. T. (2007). Optimizing BPR Plant Operations for Achieving Sustainable Low Effluent Phosphorus. New York, NY: McGraw-Hill.

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USEPA Special Evaluation Project Report. (1992). Phosphorus Removal in Lagoon Treatment Systems. Chicago: Water Compliance Branch-Technical Support Section.

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9. NR 217 EFFLUENT STANDARDS AND LIMITATIONS FOR PHOSPHORUS

Wisconsin Administrative Code NR 217 Effluent Standards and Limitations for Phosphorus (2011)

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10. NR 101 REPORTS AND FEES FOR WASTEWATER DISCHARGES

Wisconsin Administrative Code NR 101 Reports and Fees for Wastewater Discharges (2011)

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11. WISCONSIN ADMINDISTRATIVE CODE CHAPTER SPS 332

Wisconsin Administrative Code Chapter SPS 332: Public Employee Safety and Health. (2014).

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12. OSHA CFR 29 PART 1910

Occupational Safety & Health Administration (OSHA). (2012). Regulations (Standards-29 CFR 1910.1200)

www.osha.gov