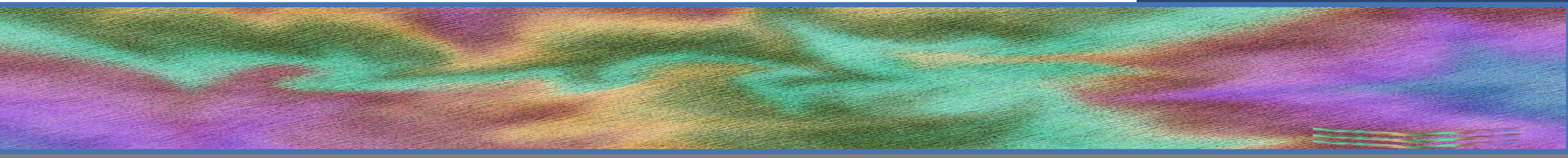

Biological Nutrient Removal

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Acronyms

Nitrogen

N	Elemental form of nitrogen
N_2	Atmospheric nitrogen (nitrogen gas)
NO_2^-	Nitrite
NO_3^-N	Nitrate
NO_x	Oxidized forms of nitrogen (nitrate & nitrite)
NH_3^-	Ammonia nitrogen
NH_4^+	Ammonium
TKN	Total Kjeldahl Nitrogen

Phosphorus

P	Elemental form of phosphorus
PO_4^{3-}	Orthophosphate
TP	Total phosphorus
H_3PO_4	Phosphoric acid

Other chemicals

O_2	Oxygen
NaOH	Sodium hydroxide
H_2SO_4	Sulfuric acid
F_3Cl_3	Ferric chloride
NaOCl	Sodium hypochlorite
Cl_2	Chlorine

Process control

BNR	Biological nutrient removal
BOD	Biochemical oxygen demand
CBOD	Carbonaceous biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
HRT	Hydraulic retention time
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
ORP	Oxidation reduction potential
PAO	Phosphorus accumulating organisms
RAS	Return activated sludge
SBOD	Soluble biochemical oxygen demand
SRT	Solids retention time
SVI	Sludge volume index
TDS	Total dissolved solids
TS	Total solids
TSS	Total suspended solids
VS	Volatile solids
VSS	Volatile suspended solids
WAS	Waste activated sludge

Other

NPDES	National Pollution Discharge Elimination System

Glossary of Nutrient Removal Terms

Acinetobacter	A common heterotrophic bacteria that functions as a phosphorus-accumulating organism (PAO) in biological phosphorus removal	A
Aerobic	A condition in which free and dissolved oxygen is available in an aqueous environment (Nitrification is an aerobic process)	
Alkalinity	The capacity of water to neutralize acids by the water's content of carbonates, bicarbonates, hydroxide, and other compounds, also known as buffering capacity	
Ammonia nitrogen	Elemental nitrogen present in the form of ammonia (NH3)	
Ammonification	The process in which soluble organic nitrogen is converted to ammonia	
Anaerobic	A condition in which free, dissolved and combined oxygen is unavailable in an aqueous environment	
Anionic polymer	A negatively charged electrolyte used as a coagulant to aid in settling solids in wastewater	
Anoxic	A condition in which oxygen is only available in a combined form, such as nitrate (NO_3), nitrite (NO_2) or sulfate (SO_4) in an aqueous environment	
Assimilation	The process in which nitrogen is taken in by cells to be used for growth and reproduction	
Autotrophic organisms	Organisms that use carbon dioxide, sunlight, or other inorganic substances for cell growth (Nitrifying bacteria are autotrophic)	
Biological nutrient removal (BNR)	The removal of nitrogen and/or phosphorus by the use of proliferation and selection of certain microbiological populations. Also See Enhanced Biological Phosphorus Removal (EBPR)	B
Biochemical oxygen demand (BOD)	The measure of the quantity of oxygen used in the biochemical oxidation of organic matter in a specified time period (usually 5 days), at a specified temperature (usually 20°C), and under specified conditions (in the dark)	
Blowoff	Turbulance in aeration tanks caused by damaged diffusers	
Carbonaceous biochemical oxygen demand (CBOD)	A quantitative measure of the amount of dissolved oxygen required for the biological oxidation of carbon-containing compounds in a sample	C
Chemical oxygen demand (COD)	A test used to measure indirectly organic compounds in water or wastewater. (The advantage of COD over BOD analyses is that COD takes only a matter of hours to complete compared to 5 days for a BOD test; the value is usually higher than BOD)	
Chlorine sponge	See "Nitrite Lock"	
Denitrification	The biological reduction of nitrate-nitrogen to nitrogen gas in an anoxic environment	D
Dissolved oxygen (DO)	Molecular oxygen dissolved in water or wastewater	

E	Enhanced biological phosphorus removal (EBPR)	The process of phosphorus removal in wastewater that relies on the proliferation and selection of a microbiological population capable of storing phosphorus in excess of their normal growth requirements. Also called Biological Nutrient Removal (BNR).
	Eutrification	Nutrient over-enrichment of a body of water, causing increased growth of algae and rooted plants
F	Fermentation	The process in which bacteria degrades organic matter under anaerobic conditions, such as in a collection system, primary clarifier, anaerobic selector or fermenter tank
	Filamentous organism	Bacterial, algal, or fungal species that grow in thread-like colonies that result in a biological mass that interferes with settling in clarifiers, or may interfere with drainage through a filter
G	Glycogen	A polysaccharide of glucose, which is energy storage inside a cell. It is present in all cells; however, microorganisms that accumulate glycogen in cells during the anaerobic stage of a bio-P process are not able to perform biological nutrient removal
	Glycogen accumulating organisms (GAOs)	Organisms that take up glycogen and volatile fatty acids during metabolism, sometimes competing with Phosphorus Accumulating Organisms for food sources.
H	Headloss	An indirect measure of loss of energy or pressure of flowing water. It is measured as the difference in elevation between the upstream water surface and the downstream water surface.
	Heterotrophic	Organisms that use organic matter (carbon) for energy and growth and can grow in both aerobic and anoxic environments using both dissolved and chemically bound oxygen (nitrates)
	Hydraulic retention time (HRT)	The given time it takes wastewater, including any return flows, to pass through a certain area
I	Ion	A charged atom, molecule, or radical that affects the transport of electricity through an electrolyte or gas. An atom or molecule that has lost or gained one or more electrons
M	Metazoan	A group of animals that may be present in wastewater having bodies composed of cells that are differentiated into tissues and organs, such as rotifers, water bears, and daphnia
	Mixed liquor suspended solids (MLSS)	The concentration of suspended solids present in activated sludge mixed liquor, usually expressed as milligrams per liter (mgl/L)
	Mixed liquor volatile suspended solids (MLVSS)	The fraction of the suspended solids in mixed liquor that can be burned off by combustion at 550° C., or the organic portion of the solids (an estimation of the microorganisms and food). Usually expressed as milligrams per liter (mg/L)
N	Nitrate	An oxygenated form of nitrogen (NO_3)

Nitrification	The process of oxidizing ammonia nitrogen to nitrate in wastewater by chemical or biological reactions.	N
Nitrifier (nitrifying bacteria)	Bacteria that are capable of oxidizing nitrogenous material, such as *nitrobacter* and *nitrosomonas*	
Nitrite	An intermediate oxygenated form of nitrogen (NO_2)	
Nitrite Lock	Incomplete nitrification resulting in excess nitrite levels that react with chlorine. Also known as “chlorine sponge”	
Nitrobacter	A group of nitrifying bacteria that oxidize nitrite to nitrate. Also called “nitrifying bacteria”	
Nitrogen	An essential nutrient that is often present in wastewater as ammonia, nitrite, nitrate, and organic nitrogen. The sum of these is expressed as Total Nitrogen	
Nitrogen cycle	The chemical transformation of nitrogen through various stages of decomposition and assimilation	
Nitrogen gas	Gaseous form of nitrogen, also called atmospheric nitrogen. It comprises approximately 79% of atmospheric gas	
Nitrogenous biochemical oxygen demand (NBOD)	The quantitative measure of the amount of oxygen required for the biological oxidation of nitrogenous material, such as ammonia-nitrogen and organic nitrogen (Measured by subtracting carbonaceous BOD from total BOD values)	
Nitrosomonas	A genus of bacteria that oxidize ammonia to nitrite. Also called “nitrifying bacteria”	
Nocardia	A group of irregularly bent, short branching filamentous organisms that cause dense dark foam in aeration basins. Associated with high fats, oils, and greases. Easily identified under a microscope.	
Nutrient	A substance that is taken in by organisms and promotes growth. Carbon, nitrogen, and phosphorus are essential nutrients to most aquatic organisms	
Nutrient ratio	The ratio of carbon, nitrogen, phosphorus and sometimes other trace elements that is essential to optimum growth of the biomass in activated sludge	
Organic	A volatile, combustible, or biodegradable compound containing carbon bound with other elements	O
Organic nitrogen	Nitrogen chemically bound in organic molecules such as proteins, amines, and amino acids. It is calculated by subtracting the Ammonia Nitrogen analysis results from Kjeldahl Nitrogen analysis results	
Organic phosphate	Phosphorus originating from organic sources, such as body and food waste, and sometimes industrial sources. Some can biologically decompose into orthophosphate; other types are non-biodegradable and will pass through the wastewater system without treatment	

O	Orthophosphate	A nutrient required for plant and animal growth. An inorganic, soluble form of phosphorus that is readily available to plants and animals without further breakdown, and accounts for 70-90% of total phosphorus in wastewater. The easiest form of phosphorus that can be treated chemically
	Oxic	A condition in which an aquatic environment contains dissolved oxygen
	Oxidation	The addition of oxygen, removal of hydrogen, or removal of electrons from a compound (For instance, organic matter may be oxidized to a more stable compound)
	Oxidation reduction potential (ORP)	The potential required to transfer electrons from the oxidant to the reductant; the quantitative measure, in mV, of the state of oxidation in wastewater treatment
P	Particulate	Solids suspended in wastewater that can vary widely in shape, size, density, and charge
	Phosphorus	An essential element and nutrient for all life forms. Occurs as orthophosphate, polyphosphate, and organic phosphates, the sum of which is Total Phosphorus
	Phosphorus-accumulating organisms (PAOs)	Microorganisms (bacteria) that uptake and store orthophosphate in excess of their biological requirements
	Polyhydroxyalkanoates (PHAs)	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 an energy source to uptake phosphorus from the wastewater in the aerobic zone of the biological phosphorus removal process.
	Polyphosphate (Poly-P)	Inorganic phosphorus derived from synthetic detergents. May be hydrolyzed into orthophosphates
	Protozoan	Small, one-celled animals such as amoebae, ciliates, and flagellates
R	Reduction	The addition of electrons to a chemical entity
	Return activated sludge (RAS)	Settled activated sludge, returned from the bottom of final clarifiers, to mix with incoming raw or primary settled wastewater.
S	Selector	A zone in a biological treatment process with specific environmental conditions that allow for the growth or lack of growth of certain microorganisms (such as an anoxic or anaerobic zone)
	Selector hydraulic retention time (HRT)	The given time it takes wastewater, including any return flows, to pass through a tank (selector)
	Short circuiting	Shortening of hydraulic detention time, such as when plant flow exceeds design flow.

Sidestreams	Sources of inflow from within the wastewater treatment facility, such as supernatant return from digesters, centrate from centrifuge thickening, filtrate from filter presses, etc. These sidestreams may be high in solids, BOD, or nutrients and may add to the plant organic or hydraulic loading.	S
Sludge age (SA)	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 (pounds) of mixed liquor suspended solids in all the biological reactors divided by the suspended solids withdrawn from the system per day (pounds per day of waste activated sludge)	
Sludge volume index (SVI)	The ratio of the volume (in mL) of sludge settled from a 1,000 mL sample in 30 minutes to the concentration of mixed liquor (in mg/L) multiplied by 1000. It indicates settling capabilities, compaction, and indication of filamentous organism overgrowth and several other indicators of process problems.	
Solids retention time (SRT)	The theoretical length of time, usually in days, that solids are retained in an aeration basin, clarifier, or other structure. Used to calculate wasting rates	
Soluble	Dissolved in a solution and more readily available for food for microorganisms, such a soluble BOD or soluble COD	
Soluble BOD (SBOD)	Soluble BOD is a sample that has been filtered through a 0.45μm filter. Soluble BOD includes volatile fatty acids (VFAs) and organic material that will readily ferment to create more VFAs in an anaerobic selector	
Spectrophotometer	Meter that uses a specific wavelength of light to measure light absorption in a sample; used for phosphorus, ammonia, nitrite, and nitrate analyses	
Struvite	Struvite is magnesium ammonium phosphate ($MgNH_4PO_4(H_2O)_6$). It forms hard, very insoluble, white, yellowish-white or brownish-white crystals.	
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)	
Supernatant	The liquid remaining above a sediment or precipitate after settling	
Total Kjeldahl nitrogen (TKN)	A laboratory analysis that measures the combined amount of organic and ammonia nitrogen	T
Total nitrogen (TN)	All forms of nitrogen including ammonia, nitrate, nitrite, and organic nitrogen	
Total phosphorus (TP)	All forms of phosphorus, including orthophosphate, polyphosphates, and organic forms of phosphorus	
Volatile fatty acids (VFAs)	Fatty acids containing fewer carbon atoms, and are dissolvable in water. 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.	V

W

Waste activated sludge (WAS)	Solids removed from the activated sludge process to prevent an excessive buildup in the system

Why do we care about nutrients in wastewater?

In Minnesota, water is an important resource that we must protect to enhance our quality of life and that of our children. Currently, many Minnesota water bodies are impaired due to nutrient-related causes, such as:

- Nitrogen
- Phosphorus
- Oxygen depletion
- Algal growth
- Ammonia
- Biological integrity
- Turbidity

Figure 1: Blue-green algae caused by excess nutrients

These impairments can cause algal blooms, fish kills, murky water, increased microbes that are harmful to human health, and the loss of desirable aquatic plants and animals.

To reduce impairments, point source dischargers, such as wastewater treatment plants, have received strict and often reduced effluent limits for nitrogen and phosphorus – the main culprits. Using chemicals to remove nutrients may prove costly and may add undesirable chemicals to the sludge and effluent.

Biological nutrient removal removes total nitrogen and total phosphorus from wastewater by:

- using microorganisms
- adjusting environmental conditions in the treatment process

What are nutrients?

Nutrients are substances essential for growth of humans, plants and animals. Nutrients are taken in by organisms and promote growth. Carbon, nitrogen and phosphorus are essential nutrients to most aquatic organisms.

Key ideas

- *Nutrients are essential to growth/life*
- *Too many can be harmful*
- *Adjusting conditions enables nutrient removal biologically*
- *Adjustment processes are not simple nor easy*

What nutrients are in wastewater and why do we need to remove them?

Contaminated wastewater from human and animal waste, infiltrated groundwater, household waste, inflow from surface water and industrial waste ends up at the wastewater treatment facility.

Phosphorus, nitrogen and carbon are nutrients that are essential to aquatic health; however, in excess they pose a serious problem. For this reason, wastewater treatment facilities must meet *nutrient effluent limits* for phosphorous, nitrogen, carbon and various micronutrients found in wastewater.

Nutrient-containing streams may cause eutrophication, ammonia toxicity and nitrate contamination of groundwater.

- **Eutrophication**: nutrient over-enrichment of a body of water, causing increased growth of algae and rooted plants and premature aging of lakes.
    - The accelerated growth of algae and rooted plants becomes a major concern as plants and algae die and decay, which in turn reduces the dissolved oxygen in the water.
    - Nitrogen and phosphorus are two necessary components for controlling eutrophication.
    - By controlling the growth-limiting nutrient (namely phosphorus or nitrogen, or both), eutrophication can be managed.
- **Ammonia toxicity**: the molecular or un-ionized form of ammonia nitrogen is toxic to fish and other aquatic life. The effect of ammonia toxicity can be acute (fish mortality) or chronic (effect on reproduction or health).
    - An un-ionized (free) ammonia concentration of 0.1 to 10 mg/L results in acute toxicity for fish species (US EPA, 1993).
- **Nitrate contamination of groundwater**: wastewater treatment systems that have the potential to discharge to groundwater also have the potential to contaminate the ground water with nitrates.
    - Nitrates can be created from the discharge of ammonia; ammonia is nitrified in the soil.
    - Nitrates are a public health concern, causing methemoglobinemia (blue baby syndrome), resulting in suffocation.

Removal of nutrients in wastewater is important to lower oxygen demand in receiving streams, protect aquatic life and eliminate eutrophication in lakes and streams and protect human health.

Carbon

Typically, carbon is measured using a test for BOD (Biochemical Oxygen Demand). BOD represents the amount of oxygen consumed during the biochemical oxidation of the organic matter. A volatile solids analysis may also be used to determine carbon content.

Humans are 18% carbon by volume; it is the fourth most abundant element on earth and is very stable. Anything organic contains carbon; sources of carbon in wastewater include anything organic but not a mineral.

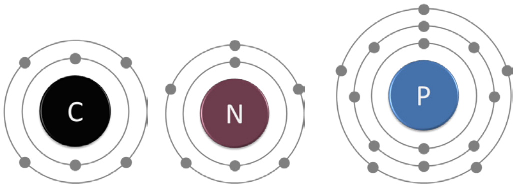


Figure 2: Carbon, nitrogen and phosphorus are the nutrients of concern in wastewater

Nitrogen and phosphorus

Nitrogen and phosphorus are the main nutrients of concern. Some facilities have received a concentration or mass limit for nutrients and others will in the future. The MPCA is developing water quality based effluent limits (WQBEL) for wastewater treatment plants that discharge upstream of an impaired water. This will result in more facilities receiving stringent effluent limits for nutrients as new water bodies are sampled and determined to be impaired. The MPCA is also developing new water quality standards as part of the triennial water quality rule revisions. These revisions will include eutrophication standards for river systems that may require future nitrogen and phosphorus limits for point source dischargers. Removing additional nitrogen and phosphorus will be a reality for many wastewater treatment facilities. Phosphorus and nitrogen can be removed biologically by adjusting conditions within the wastewater treatment facility; however, the processes to remove both are not simple.

Phosphorus

Typically, influent wastewater has a total phosphorus concentration from 5-9 mg/L and is needed in the waste stream for biological growth and treatment. Sources of phosphorus include human waste, runoff, fertilizers, detergents (banned in Minnesota although still available), food industry, water softeners and phosphoric acid (metal plating).

Phosphorus is an element in all living things; however, it is never found in elemental form and is very unstable. There are different types of phosphorus in wastewater that include Orthophosphate, Polyphosphate and organically bound phosphates. Typically, a National Pollution Discharge Elimination System (NPDES) permit deals with Total Phosphorus (TP) – a combination of all types.

Some facilities have a concentration limit in their NPDES permit for phosphorus; others have a mass limit – and some have both. Read and know your individual NPDES permit, as well as any permit that may cover your facility via a basin permit (i.e., Minnesota River General Phosphorus Permit that contains mass limits for some facilities).

Nitrogen

Nitrogen is a chemical element found in all living things. It is a constituent of amino acids, protein, DNA and RNA. Nitrogen makes up 78 percent of our atmosphere and is the seventh most abundant element on earth. Like phosphorus, nitrogen is needed to accomplish biological growth and removal.

There are different forms of nitrogen in wastewater. Total Kjeldahl Nitrogen (TKN) is the combination of ammonia nitrogen and organic nitrogen. Sources of nitrogen in wastewater include anything organic, such as human waste, urea and fertilizers.

NPDES permits include limits for ammonia nitrogen, total nitrogen or nitrate nitrogen (groundwater dischargers).

In addition to nutrients, many other constituents are found in wastewater and the list is continually growing. In recent years, the number of constituents with discharge limits has also increased. Wastewater treatment facilities are facing stricter and more numerous effluent limits.

Influent nutrient ratios

The influent values of nutrients at a wastewater treatment facility can help you determine whether you can successfully perform biological phosphorus removal. Conventional nutrient ratio in influent wastewater streams is 100:5:1 (carbon: nitrogen: phosphorus), with carbon typically being measured using COD or BOD values. Documentation indicates that a 20:1 BOD:P ratio must exist for phosphorus removal, with some studies showing up to a 100:1 ratio is needed.

BOD provides the food and the bugs for efficient removal; without it, biological phosphorus removal is not effective. If it is not present, some wastewater facilities introduce additives to the influent stream to aid in biological removal.

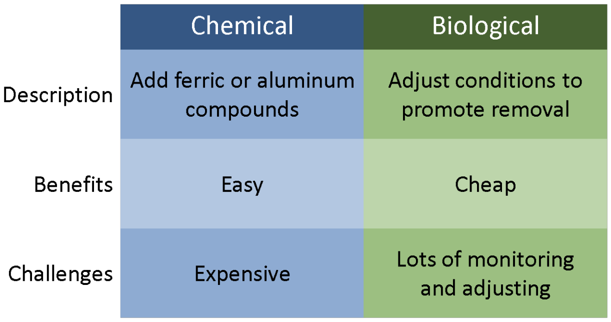
Phosphorus removal may also require a higher nitrogen ratio (100:6:1).

So, knowing your influent numbers is essential in determining your facility's ability to remove phosphorus.

Nutrient removal

Nutrients may be removed chemically, physically (through filtering) or biologically.

Both phosphorus and nitrogen can be removed biologically. In both cases, it is generally more cost effective to use biological nutrient removal technology than chemical or physical removal. However, there are other factors to weigh when deciding on a treatment technology, such as solids handling capability and existing mechanical equipment.



	Chemical	Biological
Description	Add ferric or aluminum compounds	Adjust conditions to promote removal
Benefits	Easy	Cheap
Challenges	Expensive	Lots of monitoring and adjusting

Figure 3: Benefits and challenges of chemical and biological nutrient removal

Nitrogen can be removed by a nitrification-denitrification process (explained in detail in the next section). Nitrification converts ammonia nitrogen into nitrite nitrogen as a first step and then converts nitrite nitrogen to nitrate nitrogen in a second step. Finally, denitrification converts nitrates to nitrogen gas.

Biological phosphorus removal (bio-P), sometimes called Enhanced Biological Phosphorus Removal (EBPR), is explained in detail starting on page 18. In very general terms, biological phosphorus removal is a process of manipulating the conditions in which bacteria live to accommodate phosphate accumulating organisms (PAO's) ability to take up more orthophosphate then they originally released – allowing for phosphorus removal by wasting it.

There are numerous conditions and variables involved in biological nutrient removal, including nutrient ratios, loading rates, wasting rates, dissolved oxygen and retention times, among others.

How do you remove nitrogen?

Key ideas

- *Nitrification is an aerobic process that requires a long SRT and HRT*
- *The length of the SRT is affected by temperature, dissolved oxygen, pH and ammonia concentration*
- *Denitrification is an anoxic process that requires very low dissolved oxygen with a carbon source*

Raw domestic wastewater contains around 40 mg/L of total nitrogen. This typically is measured as Total Kjeldahl Nitrogen (TKN). About 60 percent of the influent total nitrogen is ammonia and 40 percent is organic nitrogen.

Nitrogen is required for cell growth and reproduction. Bacteria take in (assimilate) nitrogen from wastewater in a process known as *assimilation*. The new biomass contains about 12 percent nitrogen.

In the aerobic treatment process, most of the organic nitrogen is changed to ammonia in a process known as *ammonification*. The ammonia is then available to the nitrifying organisms. A small portion of the organic nitrogen remains in organic form and is removed physically or will pass through to the effluent.

Biological nitrogen removal is a two-step process that involves nitrification and denitrification.

1. Nitrification is an oxidizing process that occurs in the presence of oxygen under aerobic conditions using bacteria (often *Nitrosomonas*) to oxidize ammonia to nitrite, and then using another type of bacteria (often *Nitrobacter*) to oxidize the nitrite (NO_2) to nitrate (NO_3)

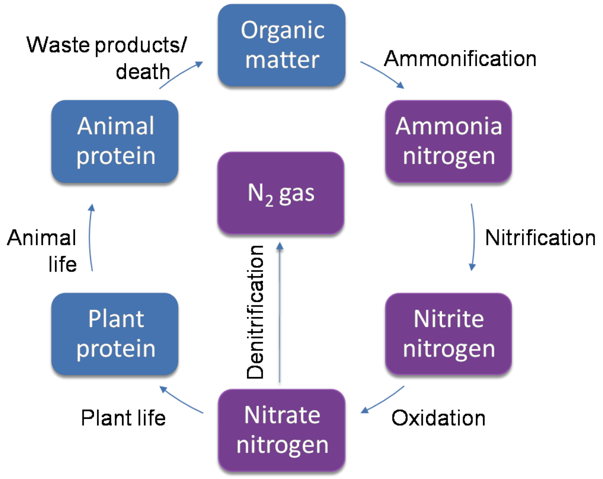


Figure 4: The nitrogen cycle; purple boxes show wastewater portion of cycle

Ammonia + Oxygen + Alkalinity + *Nitrosomonas* = Nitrite
(NH_3) (O_2) (NO_2)

Nitrite + Oxygen + Alkalinity + *Nitrobacter* = Nitrate
(NO_2) (O_2) (NO_3)

2. Denitrification is a reducing process that occurs in the absence of oxygen under anoxic conditions using heterotrophic bacteria (usually *Pseudomonas*) to reduce nitrate to nitric oxide, nitrous oxide and nitrogen gas

Nitrate + Organics + *Pseudomonas* = Nitrogen gas + Alkalinity
(NO_3) (N_2)

Nonbiodegradable organic nitrogen that is in particulate form is not removed through these processes, but rather through the physical process of solids separation (sedimentation or filtration).

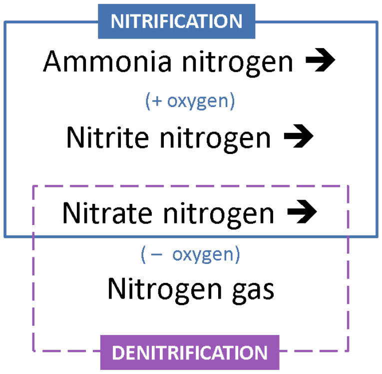


Figure 5: Nitrogen can be removed by a nitrification/denitrification process.

Conditions necessary for good removal of nitrogen

Nitrification

For optimum nitrification, strive for these conditions:

- A solids retention time (SRT) long enough to allow a stable population of nitrifiers to be maintained in the process. The target SRT will vary with temperature, DO, pH, and ammonia concentration.
    - Temperature must be greater than 7^{o} C to provide a stable population of nitrifiers.
    - Dissolved Oxygen above 2.0 mg/L generally will not limit nitrification.
    - Nitrifiers perform poorly with wide swings in pH, so maintain pH between 6.8- 8.0.
    - Nitrification process will consume alkalinity at a rate of 7.14 mg $CaCO_3$ per 1 mg nitrogen. An effluent alkalinity of at least 50 mg/L and preferably 100 mg/L is recommended to stabilize the pH in the system.
- A hydraulic retention time (HRT) long enough to allow biomass enough time to react with the ammonia. Systems with longer HRTs are less likely to see ammonia break-through due to temperature changes, variation in flow and loading.

- Nitrifiers are sensitive to many organic and inorganic substances, so eliminate toxic substances from the system.

Single Sludge Systems remove BOD and ammonia in the same reactor with only one set of clarifiers. Single sludge systems are common because many times denitrification is incorporated into the design, which would require the mixing of sludge or the addition of a carbon source.

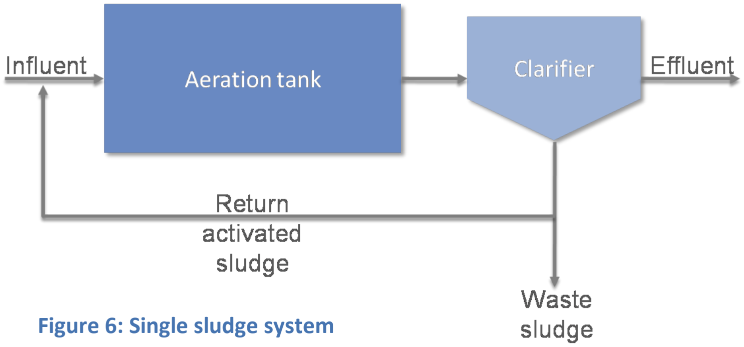


Figure 6: Single sludge system

Separate Sludge Systems remove BOD in one set of reactors and clarifiers and remove ammonia in subsequent sets of reactors and clarifiers. Separate sludge systems protect the slow growing nitrifiers from influent wastewater that contains toxic materials and allow optimizing the nitrification system. They are less common because of higher construction costs and the incorporation of denitrification.

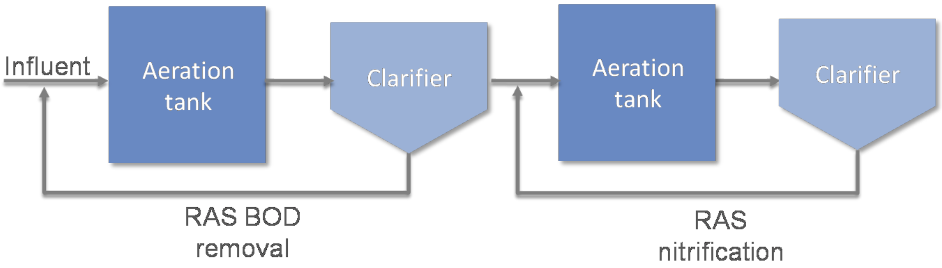


Figure 7: Separate sludge system

Denitrification

For optimum denitrification, these conditions are necessary:

- An anoxic zone that has dissolved oxygen levels less than 0.1 mg/L. Denitrifying bacteria are facultative and prefer to use oxygen to metabolize CBOD. Any oxygen in the zone will be used before the bacteria start to reduce the nitrate.
- Sufficient readily degradable CBOD in the anoxic zone. Denitrification consumes 2.86 mg CBOD per mg of nitrate denitrified. Carbon augmentation may be necessary with low CBOD to nitrogen ratios and nearly all separate stage denitrification.

There are benefits to combined nitrification and denitrification:

- Denitrification will reduce 2.86 mg of the CBOD per mg of nitrate without the expense of adding air.
- Reduce the alkalinity demand by producing 3.57 mg of alkalinity per mg of nitrate denitrified.

A Wuhrmann Process is a single sludge nitrification system followed by an anoxic zone for denitrification. This system is limited by the lack of a carbon source in the anoxic zone also requires more alkalinity to maintain a steady pH in the aeration tank. Nitrogen gas in the clarifier inhibits settling.

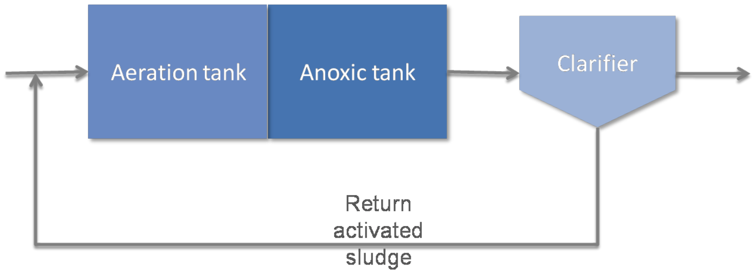


Figure 8: Wuhrmann process

A Ludzack-Ettinger process places the anoxic zone upstream of the nitrification reactor to take advantage of the carbon source in the influent. Nitrates are introduced to the anoxic tank through the RAS. This system reduces the alkalinity demand and reduces CBOD without the expense of adding air in the anoxic zone. The system is limited by the amount of nitrate returned in the RAS.

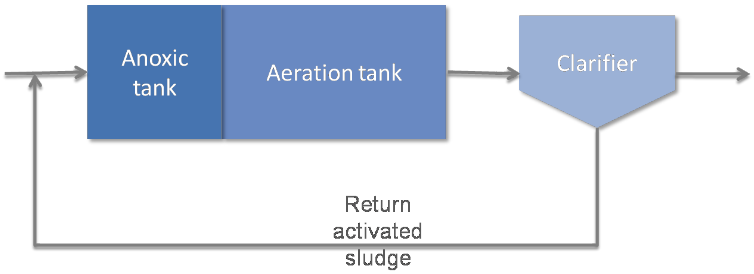


Figure 9: Ludzack-Ettinger process

A Modified Ludzack-Ettinger process adds a mixed liquor recycle from the end of the aeration tank to the beginning of the anoxic tank. This returns more nitrates to the anoxic zone increasing the nitrogen that is removed. High recycle rates can introduced dissolved oxygen in the anoxic zone and dilute the substrate thereby reducing the performance.

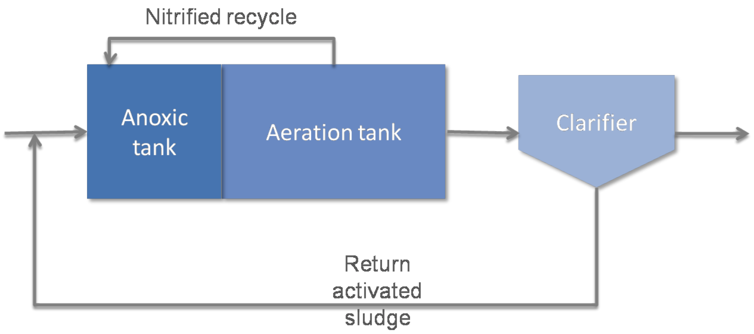


Figure 10: Modified Ludzack-Ettinger process

Four-stage Bardenpho process

The four-stage Bardenpho process basically uses the principles of the modified Ludzack-Ettinger process for the first two stages and the Wuhrmann process for the final two stages to achieve a high level of total nitrogen removal.

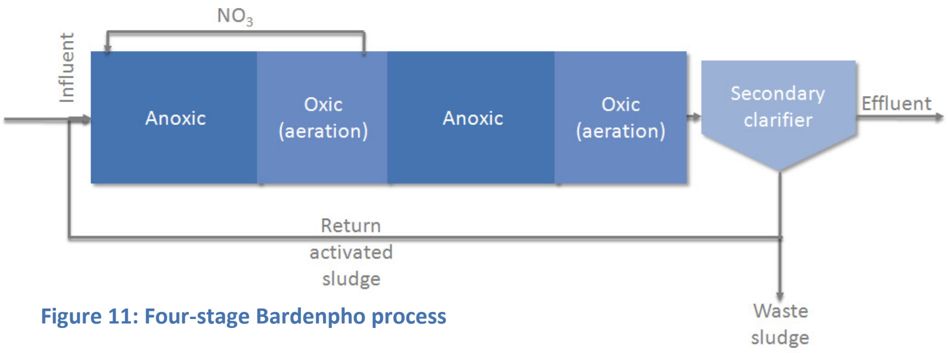


Figure 11: Four-stage Bardenpho process

Oxidation ditches

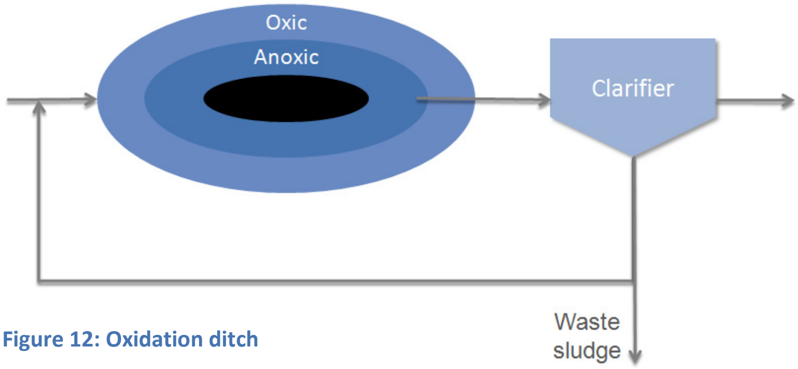


Figure 12: Oxidation ditch

Oxidation ditches can perform biological nitrogen removal by creating an anoxic zone in parts of the ditch. This configuration is like Wuhrmann process. By changing the location of the aerators and mixers the oxidation ditch can operate like the Bardenpho process or the Modified Ludzack-Ettinger process. The oxidation ditch can create high recycle rates without the need for pumping the return.

Sequencing Batch Reactors (SBR)

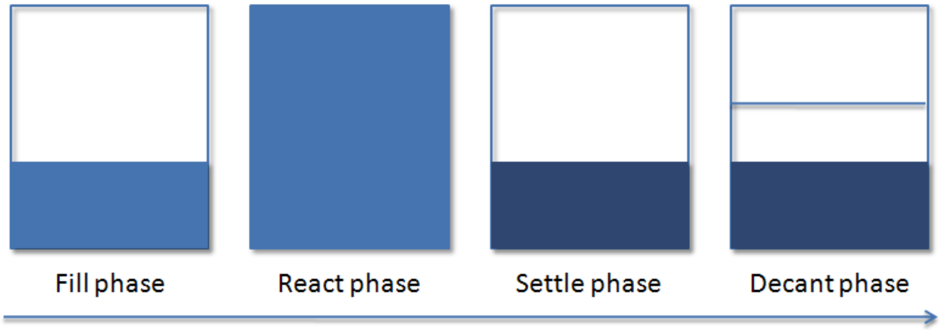


Figure 13: Sequencing batch reactors

SBR perform all the necessary functions of nutrient removal in a single tank with variable water levels and timed aeration. This system requires a minimum of three tanks and advanced automation equipment to control the cycle times and phases. The SBR control systems allows the operation to be configured to operate as almost any other suspended growth reactor by adjusting the cycle phases between fill, mix, aerated, settle and decant.

Biological phosphorus removal

Phosphorus stimulates the growth of plants, both on soil and in water. If an excess of phosphorus enters a water body, algae and aquatic plant growth can become unmanageable, choke up the waterway and use large amounts of oxygen. The lowered dissolved oxygen levels may harm aquatic life. For this reason, reducing the amount of phosphorus in wastewater effluent is essential.

Key ideas

- *Phosphorus in wastewater occurs in several forms*
- *Biological phosphorus removal uses microorganisms*
- *Adjusting the amount of oxygen present is crucial*
- *There is more than one way to configure a plant to enable biological phosphorus removal*

Phosphorus-removal techniques can take advantage of microorganisms to remove phosphorus from wastewater. This process is called *biological phosphorus removal*. Biological phosphorus removal is possible because of the microorganism's ability and need to utilize phosphorus in energy transfer and for cell components.

Where does phosphorus in wastewater come from?

Almost half comes from human waste, but industrial process wastewater and food soils are significant sources as well. The rest comes from multiple sources, such as water treatment, household cleaners and even toothpaste.

Most phosphorus in wastewater occurs as:

- Orthophosphate – the simplest form consisting of individual molecules of phosphate
- Polyphosphate – large molecules containing many individual molecules of orthophosphate
- Organic phosphate – phosphate combined with an organic compound, such as human waste

During biological treatment, most polyphosphate and organic phosphate is converted to orthophosphate, a form that is readily assimilated by microorganisms.

How do you remove phosphorus?

Table 1: Phosphorus in domestic wastewater

Phosphate form	Typical conc. (mg/L)
Orthophosphate, PO_4^{-3}-P	3.0 – 4.0
Polyphosphates	2.0 – 3.0
Organic phosphates	0.7 – 1.0
Total as P	5.7 – 8.0

Source: EPA

In wastewater effluent, 'total phosphorus' includes both soluble and particulate phosphorus. Like organic particulate nitrogen, particulate phosphorus is removed using a solids removal process.

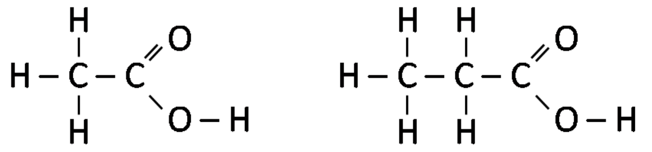
Removing soluble phosphorus requires use of a biological process employing organisms that can store excess phosphorus (called 'phosphorus-accumulating organisms' or 'PAOs'). Usually, the PAOs, under anaerobic conditions, convert organic matter to energy-rich carbon compounds called Polyhydroxyalkanoates (PHAs). Energy required for this process is generated through breakdown of polyphosphate molecules, resulting in an increased concentration of phosphate in the anaerobic state (phosphorus release). Under aerobic conditions, energy is restored through phosphate uptake.

Phosphate-accumulating organisms

Some bacteria are able to store more polyphosphate than what they need for biological growth. These bacteria are called phosphate accumulating organisms (PAOs). Since PAOs grow best on volatile fatty acids (VFAs), to ensure an adequate population of PAOs, you must ensure adequate availability of their food source – VFAs.

Volatile fatty acids

VFAs are the smallest molecules into which organic material can be broken down. VFAs consist primarily of acetic and propionic (propanoic) acids. VFAs are formed through fermentation, which can occur in the collection system, in primary clarifiers or in fermentation tanks. The bio-P removal process removes 7 to 10 mg of VFAs for each mg of P that is removed. If enough VFAs are not produced naturally, chemical addition may be required to ensure adequate PAO population for optimum bio-P removal.



Acetic acid, CH_3COOH Propionic acid, CH_3CH_2COOH

Figure 14: VFAs -- Acetic and propionic acid

VFAs can be affected by recycle flows:

- RAS return high in NO_3 to anaerobic zone will interfere with fermentation, reducing the amount of VFAs.
- Recycle from sludge handling can contain high quantities of nitrogen and phosphorus. (nitrate reduction in the anaerobic zone utilizes substrate otherwise available to the PAOs and there is no sense in reintroducing phosphorus you have already taken out and it may require more VFAs)
- Using air lift pumps to return activated sludge produces aeration and will introduce oxygen into the anaerobic zone
- Although you have no control over the formation of VFAs in the collection system, there are ways to maximize VFA formation in primary clarifiers:
    - Keep a higher blanket (storing sludge longer in the primary clarifier will promote fermentation and produce more VFAs)
    - Avoid drops in effluent channels that add O_2 (turbulence of water being added to anaerobic zone will add oxygen and impair the process)

PAOs in anaerobic conditions

Under anaerobic conditions, the PAOs use stored polyphosphate as a source of energy for taking up and storing food. During the process of taking up and storing food, the polyphosphate used for energy is split apart into molecules of orthophosphate. These molecules cannot cross the cell membrane by themselves because they are negatively charged (anions). However, during the process they bond with magnesium and potassium, which are positively charged (cations). During bonding, the charges are neutralized; then they can cross the cell membrane and pass from the cell into the wastewater. This process, called *phosphorus release*, also releases magnesium and potassium into the wastewater. Magnesium and potassium cations are generally found in sufficient quantities in domestic wastewater to allow bonding to take place.

To perform biological P removal, you must ensure:

- There is sufficient organic carbon and phosphorus in the secondary influent
- The anaerobic zone is sized correctly
- There are sufficient cations (magnesium and potassium) to facilitate phosphorus release and uptake

The minimum requirements needed in the anaerobic zone are

- A BOD_5 to total phosphorus (TP) ratio of 20:1
- A hydraulic detention time (HDT) in the anaerobic zone of about one hour (Do not run out of VFAs for the bio-P bugs. Secondary release of phosphorus occurs when the PAOs are under anaerobic conditions in the absence of a source of VFA. The energy stored as polyphosphate is used for cell maintenance and phosphorus is released to the liquid phase. Upon re-aeration, there will be no stored food to supply energy for the uptake of phosphorus.)
- A solids retention time (SRT) in the anaerobic zone of about one and a half to two days (allow just enough time for the enhanced biological phosphorus removal reactions to take place)

The characteristics of the wastewater entering the anaerobic zone determine the effluent phosphorus concentration that is possible.

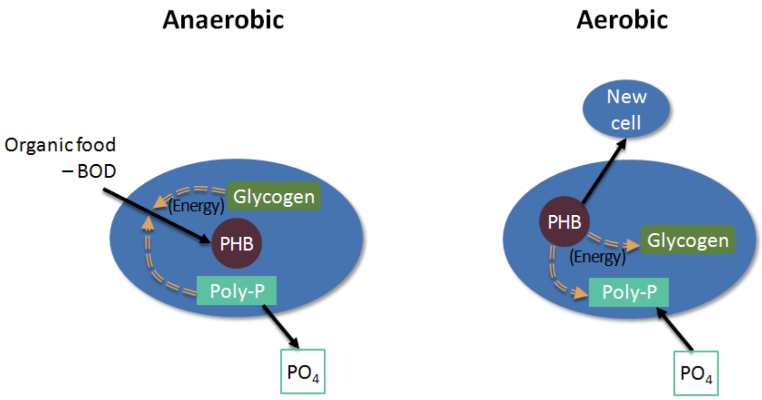


Figure 15: Mechanism of biological phosphorus removal

PAOs in aerobic conditions

Under aerobic conditions, PAOs take up orthophosphate using energy from the oxidation of organic matter by nitrate or dissolved oxygen and convert it to polyphosphate, which is stored in their cell. PAOs take up more orthophosphate than they released under anaerobic conditions. This is called *luxury uptake*.

Phosphorus is then removed from the system through wasting of the mixed liquor – waste activated sludge (WAS).

Cycling of wastewater through anaerobic and aerobic zones acts as a selector and favors the growth of PAOs.

Selective advantage

The anaerobic conditions and the volatile fatty acids favor the growth of PAOs and give them a selective advantage over other microorganisms in the system. Other groups are put at a temporary disadvantage with respect to access to food. However, another group of microorganisms, the glycogen accumulating organisms (GAO), co-exist with the PAOs and also have the ability to take up VFAs in the anaerobic zone. Under certain conditions, the GAOs may be able to out-compete the PAOs which will result in less uptake of VFA by the PAOs and less release of phosphorus in the anaerobic zone. This in turn will result in less overall phosphorus removal.

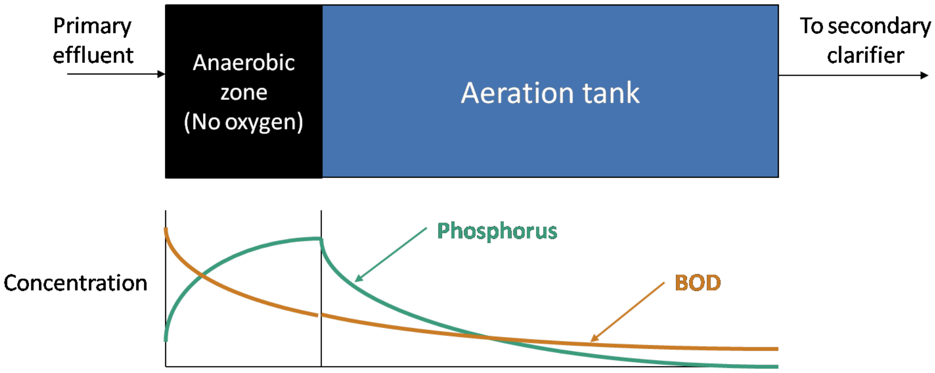


Figure 16: Bio-P bacteria selected by passing activated sludge through an anaerobic zone (no oxygen) followed by an aerobic zone

The following conditions would favor the growth of GAO over PAO:

- High SRT
- High temperature (>28C)
- Longer non-aerated zones
- Stronger wastes with low TKN content
- Periods of intermittent low BOD loads
- Low pH in the aerobic zone (keep pH above 7.2)

Conditions necessary for good bio-P removal

Six conditions are necessary for good bio-P removal:

1. Sequential anaerobic and aerobic exposure of mixed liquor.
2. Available VFAs in the anaerobic zone. A BOD_5 to TP ratio of 20:1 or 7-10 mg/L of VFAs are required per mg of phosphorus removed by bio-P.
3. Waste biomass when the MLSS is aerobic and the phosphorus is stored in the cell mass.
4. Avoid secondary release of phosphorus. Anaerobic zones should have a hydraulic detention time of about one hour, depending on MLSS. concentration and a solids retention time (SRT) of 1.5 – 2 days. Monitor sludge blanket in secondary clarifier so it doesn't go anaerobic and release phosphorus.
5. Take care in managing recycle streams. Recycle from sludge handling can contain high quantities of nitrogen and phosphorus.
6. Minimize dissolved oxygen and nitrate recycled back to the anaerobic zone. Dissolved oxygen and nitrate will interfere with fermentation. Avoid producing aeration through pumping and turbulence between tanks.

Enhanced biological phosphorus removal design configurations

Although there are many design variations for biological phosphorus removal systems, all of them incorporate anaerobic and aerobic zones. The main goal of all of the configurations is to minimize nitrate return to the anaerobic zone.

Anaerobic/oxic (A/O) configuration

The anaerobic/oxic (A/O) configuration was developed originally as the Phoredox system in South Africa in 1974 and later patented in the United States under the name A/O. This system is similar to a conventional activated sludge process with an anaerobic zone at the head of the secondary train. This system is used where ammonia removal is not required so nitrates are not being returned to the anaerobic zone.

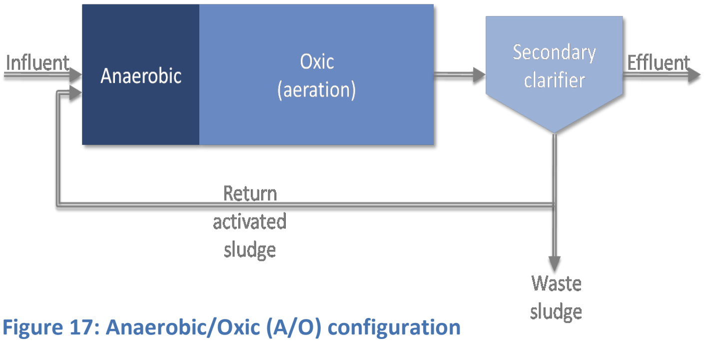


Figure 17: Anaerobic/Oxic (A/O) configuration

Anaerobic/anoxic/oxic (A^2O) configuration

A variant of the A/O configuration is the anaerobic/anoxic/oxic (A^2O) process where an anoxic zone is situated between the anaerobic and aerobic zones. Nitrate rich MLSS is returned from the end of the aerobic zone to the anoxic zone for denitrification prior to RAS being returned to the anaerobic zone.

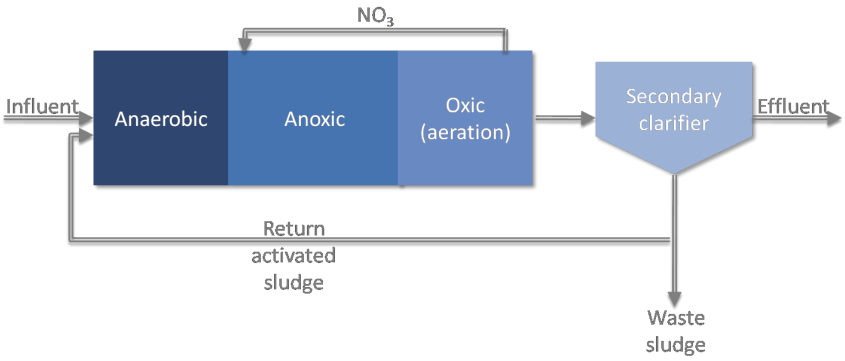


Figure 18: Anaerobic/anoxic/oxic (A^2O) configuration

Modified Bardenpho configuration

The modified Bardenpho configuration is a modification of the A^2O process with additional anoxic and aerobic zones situated at the end of the secondary train. This was developed for additional nitrogen removal and consequently minimal nitrate return to the anaerobic zone.

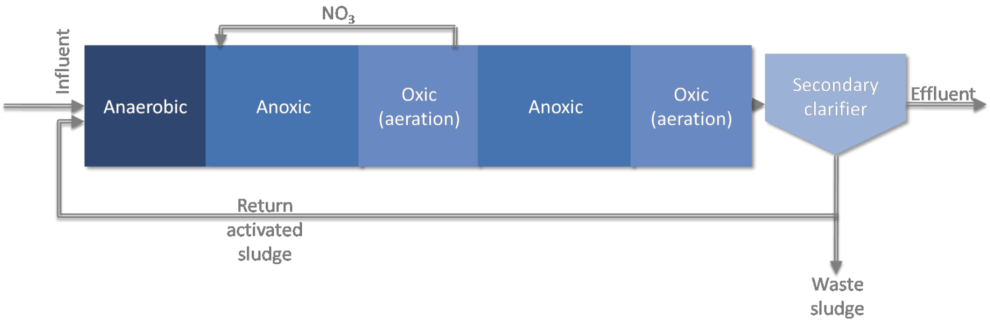


Figure 19: Modified Bardenpho configuration

University of Cape Town (UCT) configuration

Another modification of the A^2O process is the University of Cape Town (UCT) configuration. This process returns both nitrate rich MLSS from the end of the aerobic zone and RAS from the secondary clarifier to the head of the anoxic zone for denitrification. MLSS from the end of the anoxic zone is then returned to the head of the anaerobic zone. The goal is to minimize nitrate return to the anaerobic zone. The modified UCT configuration uses a second anoxic zone that receives the return of nitrate rich MLSS from the end of the aerobic zone.

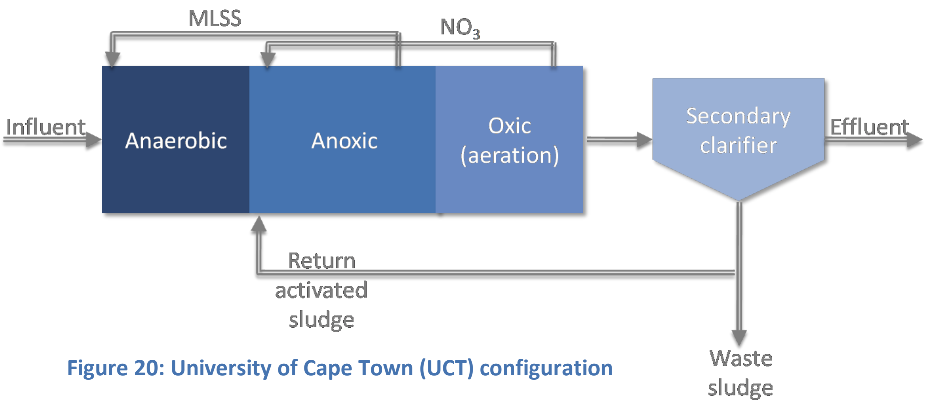


Figure 20: University of Cape Town (UCT) configuration

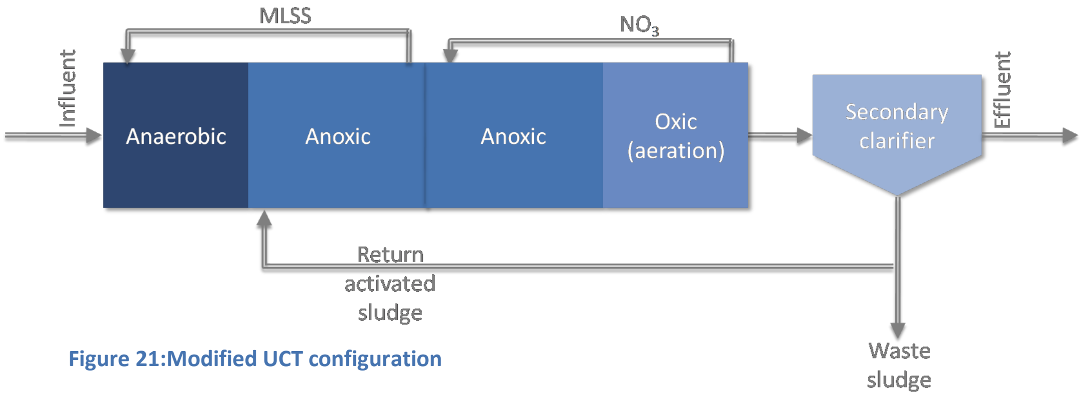


Figure 21:Modified UCT configuration

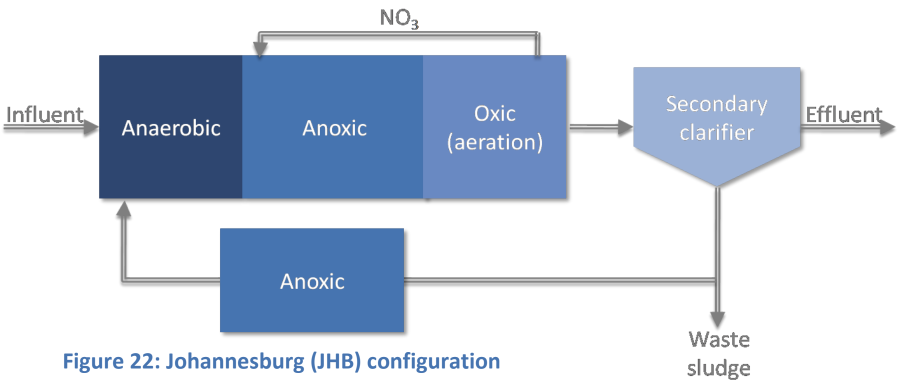


Figure 22: Johannesburg (JHB) configuration

Johannesburg (JHB) configuration

The Johannesburg (JHB) configuration has a separate anoxic zone on the RAS line for denitrification before return to the anaerobic zone.

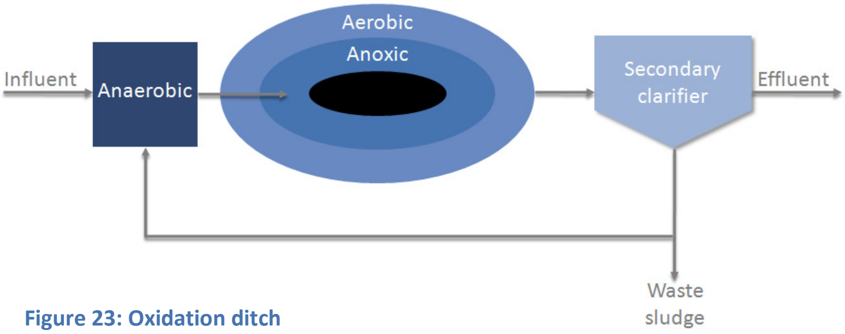


Figure 23: Oxidation ditch

Oxidation ditches

Oxidation ditches can perform biological removal by creating anaerobic and anoxic zones in parts of the ditches.

Monitoring and process control analyses

Biological Nutrient Removal (BNR) requires constant monitoring, evaluating and tweaking because the work is being done by living organisms and conditions for those organisms change daily. Temperature, mixed liquor suspended solids, food levels coming into the plant (influent BOD and volatile fatty acids) and many other factors affect this process.

Key ideas

- Process control is essential to successful biological phosphorus removal
- Monitoring and collecting data over time develops control parameters
- Influent components may change, so process control analyses will guide operational changes

When monitoring, some analyses are helpful, but many are essential to ensure enough of the right organisms are present. Essential analyses include:

- Dissolved oxygen
- Temperature
- pH
- Solids
- BOD or CBOD
- Phosphorus
- Nitrogen
- Microscopic examination

Helpful analyses include:

- Oxidation-reduction potential (ORP)
- Alkalinity
- Soluble COD
- Volatile fatty acids

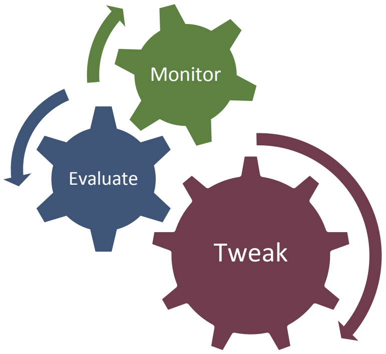


Figure 24: Three parts to process control

Each of these will be discussed in further detail.

To keep the nitrifying and denitrifying bacteria and Phosphorus Accumulating Organisms (PAOs) happy and prevent the Glycogen Accumulating Organisms (GAOs) from dominating, the operator needs to:

- provide proper oxygen control and plenty of food for the amount of organisms present in the system
- maintain other optimal environmental factors
- monitor the influent levels of the nutrients to be removed

Note: Monitoring influent levels may lead to requiring phosphorus and nitrogen limits of industries and commercial establishments through the use of ordinances as a preliminary measure. Each system will require somewhat different parameters, but the following information will provide a general guide. Refer to Table 6 on page 38 for areas of sampling, optimal parameters and monitoring frequency.

Data analysis is a vital tool for showing optimal conditions for BNR, and also for predicting and avoiding process problems. The use of a computer program with charting capabilities, such as Excel, can make visual observation of trends easy and user-friendly.

Nutrients

An operator will need to know the approximate levels of nitrogen and phosphorus coming into the plant (influent) and leaving the plant (effluent). Since sidestreams and septage intake are also potential sources of high nutrient loading, they should also be tested. Because the standard certified analyses for these tests are somewhat time-consuming, you may want to use either a small hand-held spectrophotometer that will analyze ammonia nitrogen and phosphorus, or small test kits, which are not as accurate. The choice will depend on your budget and the accuracy desired.

Essential monitoring

- **Phosphorus**
- **Nitrogen (all forms)**
- **Dissolved Oxygen**
- **Temperature**
- **pH**
- **Solids**
- **BOD or CBOD**
- **Microscopic examination**

Figure 25: Essential monitoring for a well-run nutrient removal process

If your permit limit is quite low, you will want to use a method that is fairly accurate. If you already own a spectrophotometer to analyze chlorine in the water supply, your supplier may have reagents for ammonia nitrogen and orthophosphate (sometimes called reactive phosphorus) analysis with your instrument. Make sure that the accuracy of the reagents or kit is within the target test range. For example, you may want a reagent kit that is accurate from 0.01 – 2.0 mg/L for your effluent, but another kit that is 2.0 – 20.0 mg/L for your influent. By comparing the test kits to the actual analysis by a contract laboratory, an operator can develop a fairly accurate multiplier to use for estimating nitrogen and phosphorus.

Phosphorus accumulates on glassware, so you may want to clean all glassware used for phosphorus analysis with a non-phosphate soap, rinse with a 10% hydrochloric acid solution, and then rinse well with distilled water. Since most city water supplies contain some phosphorus, many over 1 mg/L, *always* used distilled or deionized water for analyses.

Although some of these methods are not acceptable for certification – you cannot use the results for your Discharge Monitoring Report (DMR) – they are fine for process control. Total phosphorus, a combination of all types of phosphorus, is usually the form that you will be required to analyze for your DMR. If you can purchase reagent kits for nitrate and nitrite nitrogen, you will have even more monitoring ability.

This section covers basic essential process control for biological nitrogen and phosphorus removal, as well as more advanced process control monitoring. The Standard Methods numbers are in Table 4 on page 35 but for the use of “quick” process control tests kits and equipment, use the manufacturer’s methods for analyses.

Phosphorus

Orthophosphate (reactive phosphorus) is the quick no-digestion analysis that you can do with any spectrophotometer and the reagents for reactive or orthophosphate. There may be some calculations involved with the kit; also remember that orthophosphate is approximately 0.75 of total phosphorus. Condensed and organically-bound phosphorus in the influent will be converted to orthophosphate during the BNR process. Phosphorus is then removed from the process through activated sludge wasting. So, total phosphorus in the effluent will be primarily orthophosphate, although there will be some organic phosphorus contained in any effluent suspended solids. The analysis for orthophosphate is quick and easy: a coloring reagent is added to the sample (it may have to be diluted if high in phosphorus) and then a spectrophotometer is used to determine the mg/L orthophosphate. Remember that some reagent kits may require additional conversions in the calculation to total phosphorus.

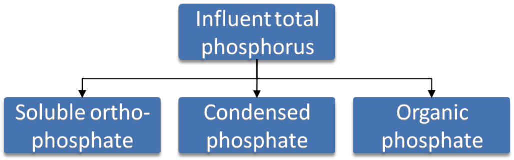


Figure 26: Phosphorus in influent

Total phosphorus is basically the same as the orthophosphate analysis with an extra digestion step. A small COD digestion unit works well for this, and pre-measured reagents may be purchased in a sealed cuvet ready for digestion. Conduct this analysis under a fume hood as the fumes from the digester process are toxic. Typical influent total phosphorus levels are 5-9 mg/L. If influent levels exceed this, sample contributing industries and commercial establishments, such as car washes, to determine the source.

Nitrogen

Ammonia nitrogen is analyzed for DMR reporting with a preliminary distillation and then spectrophotometric, titrimetric, or Ion Selective Electrode (ISE) analysis. You will be required to do a distillation study before becoming certified for this analysis. The study determines whether distillation is necessary. If a laboratory is analyzing an assortment of samples, especially industrial wastes, they will usually be required to distill the sample. The spectrophotometric analysis is simple and gives fairly accurate results at low levels, depending on the equipment and reagent kits used.

If ammonia nitrogen levels are high in the influent (over 40 mg/L), look at the industrial or commercial sources.

Nitrate and nitrite nitrogen Nitrite nitrogen is analyzed by a spectrophotometric method. Nitrate nitrogen is also analyzed spectrophotometrically, but with an additional step: the sample is reduced from nitrate (NO_3) to nitrite (NO_2) by filtering it through a cadmium reduction column in a preliminary step. Carefully monitor the return activated sludge (RAS) to ensure that no nitrate is being sent back to the anoxic zones.

- If there is nitrate in the effluent, the plant is not denitrifying. Find and correct the source of the problem.

- If there is nitrite in the effluent, chlorination will be inhibited due to the process “sticking” at a partial nitrifying level. (Toxic substances, high pH, or high temperatures may sometimes cause this situation.) Find and correct the source of the problem.

There should be little or no nitrate or nitrite in the plant influent.

Total Kjeldahl Nitrogen (TKN) is the total of ammonia nitrogen and organic nitrogen. High effluent TKN with high ammonia nitrogen may indicate the inability to nitrify ammonia, which may be caused by many different factors. High TKN with low ammonia nitrogen may be caused by the inability of the microorganisms to break down compounds that are part of the organic nitrogen. The analysis for TKN involves digestion. The main difference between the two methods, micro- and macro-Kjeldahl, is levels of TKN in the sample and sample size.

Dissolved oxygen (DO)

Those operating an activated sludge facility likely already have a field dissolved oxygen (DO) meter. This meter has a submersible probe and a long cable allowing you to test the dissolved oxygen in the basins. Since the dissolved oxygen levels in biological nutrient removal selector zones are critical, proper calibration is essential. Some of the newer facilities have in-line DO meters; these may also require frequent calibration to maintain accuracy. Monitor each zone (selector) as frequently as possible for DO. At the end of the basins,

Table 2: Optimum dissolved oxygen levels in zones

Zone	DO level
Anaerobic	0.0
Anoxic	0.0 – 0.1 mg/L
Oxic	1.5 – 2.0 mg/L

- Anaerobic zones should contain 0.0 mg/L
- Anoxic zones should contain approximately 0.1 mg/L
- Oxic zones should contain less than 2.0 (preferably 0.5-1.0 mg/L)

Since roughly 4.3 milligrams of oxygen are used for every 1 mg of ammonia nitrogen oxidized into nitrite and nitrate nitrogen, the oxic zones require more oxygen and monitoring is critical. Also, the higher the DO is in the return activated sludge brought into an anaerobic or anoxic zone, the more difficult it will be to do biological removal. So, monitor the RAS as it returns to the anaerobic or anoxic zones.

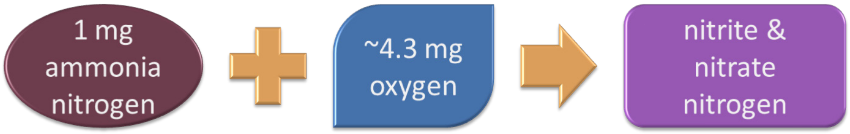


Figure 27: Oxic zones require more oxygen and monitoring is critical

Temperature

Temperature in the basins and selectors is critical for optimum biological nitrogen removal. Nitrification and denitrification shut down around 7°C; high temperatures may also cause problems. *Nitrobacter* is more temperature sensitive than *Nitrosomonas*. When *nitrobacter* shut down it may cause nitrite “locking”, indicated by higher chlorine demand (also called “chlorine sponge”). The microorganisms responsible for biological phosphorus removal are not as sensitive to temperature as the nitrifiers. Although it may seem as though an operator cannot control ambient air temperature, s/he can control the amount of MLSS in the system. The higher the MLSS, the higher the temperature in the basin due to the metabolism of the microorganisms. A simple way to analyze the temperature in the selectors is to use the thermometer on your DO meter. Record temperatures at least once daily to establish an overall picture of optimum conditions for nitrogen removal at your facility.

pH

Microorganisms used for BNR are sensitive to pH changes, with *nitrobacter* that change nitrite to nitrate being the most sensitive. Nitrification reduces alkalinity levels which can drop pH significantly. The addition of any phosphorus-removal chemicals also may drop the pH, making it difficult to do any biological removal. Microorganisms prefer neutral: pH = 7.0. The optimum pH for biological nutrient removal is 6.8 – 7.2. High or low pH wastes received from an industry may adversely affect pH and BNR.

- A pH of 7.4 or higher combined with high influent ammonia nitrogen could create a toxic environment in the system.
- Septage, anaerobic influent, or anaerobic sidestreams are typically acid and will lower pH.

The pH analysis must be done immediately; it cannot be sent in to a commercial laboratory. Use of either a bench-top meter or a hand-held model is fine. However, the meter must be calibrated with two buffer solutions that bracket the pH to be tested, and fresh buffer solution must be used each time the meter is calibrated.

Solids

Solids are critical analyses for any activated sludge facility, whether or not they are doing BNR. The analyses are simple, and can be completed in a matter of minutes or hours, depending on the method. Suspended or non-filterable solids have many uses for process control. The total solid analysis is the analysis preferred for biosolids or other solids that are difficult to filter. Volatile solids indicate the organic portion of the sample, or the food and microorganisms. Since the non-volatile portion cannot be easily broken down in the system, the volatile solids analysis is useful for understanding how many solids are available for treatment.

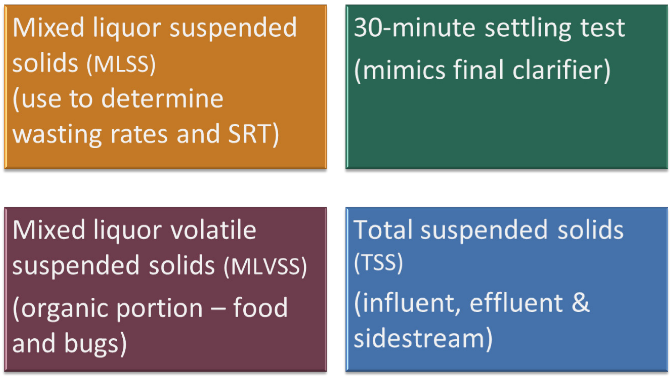


Figure 28: Types of solid analyses

Total suspended solids (TSS)

For suspended solids analysis, the operator may use an atmospheric oven set at 103-105° C or a solids centrifuge. Although the oven method is more accurate, the centrifuge method is less expensive and faster. Also, the operator will have to periodically compare the centrifuge tube readings to an oven method TSS to determine the estimate of solids.

- For the oven method, weigh a filter on an analytical balance and record the weight. Place the filter in a filtration apparatus and wet it down with distilled water. Place a specific amount of the sample in the apparatus and filter it. The solids are retained by the filter. Then, place the filter in the oven to dry for at least one hour. Finally, remove it, cool it in a dessicator, and then reweigh. Use the weight of the filter without the sample in milligrams, the weight of the filter with the sample (in mg.), and the size of the sample in milliliters to calculate the mg/L total suspended solids of a sample.
- For centrifuge analysis, place a liquid sample (usually 25-50 mL) into the centrifuge tubes, spin the sample at high speed for 15 minutes, and then compare the amount of solids at the bottom of the tube, in mL, to a reference chart for estimated suspended solids.

Effluent TSS in a BNR process contains significant amounts of phosphorus. By monitoring TSS in effluent, an operator can estimate whether the effluent phosphorus levels are high. TSS in return streams will also contribute to phosphorus loading, so monitor any sidestreams such as thickener return, digester supernatant, or other decant that is returned to the head of the plant, especially if it is returned directly into the aeration basins. Eliminating or lowering effluent TSS is essential in meeting effluent permit limits.

Mixed liquor suspended solids (MLSS)

MLSS is an essential analysis for process control of BNR systems, as it is used to calculate the wasting rate, and thus the Solids Retention Time (SRT). Also, the MLSS analysis is required for the calculation of the Sludge Volume Index – an indicator of how well the sludge is settling in a final clarifier – and whether filamentous organisms are beginning to predominate.

The MLSS is an estimation of the amount of microorganism and other organic matter in aeration. Allowing the MLSS to get too high or low may negatively affect the BNR process. Most facilities calculate wasting by maintaining a specific Solids Retention Time (SRT), although some prefer to maintain a constant MLSS if the influent is consistent.

Waste activated and return activated suspended solids (WASSS and RASSS)

WASSS and RASSS are the same analysis as MLSS, but are of the WAS and RAS solids. These process control analyses are essential to calculate wasting and return rates.

Volatile solids

Volatile solids are sometimes used to determine a more accurate level of organic matter (microorganisms and food) in the mixed liquor. This is usually used for the Food-to-Microorganism ratio (F:M). Since BOD, a five-day analysis, is also used in the F:M calculation, it is not considered effective for day-to-day process control. However, knowing the volatile portion of the mixed liquor will help you determine whether insufficient food or too much grit and other inorganic debris are entering the system, such as from an industry or sewer line break. To do the analysis, weigh a heat-resistant glass filter in a porcelain-filtering crucible, filter a known amount of sample through it, and then place it in a muffle furnace at 550°C for a specified amount of time. (The furnace must be set under a fume hood or other venting system.) Cool the crucible in a dessicator, weigh it, and then calculate the Mixed Liquor Volatile Suspended Solids (MLVSS) of the sample. MLVSS is usually 75% of the total MLSS.

Dissolved solids

Dissolved solids are the solids that pass through the filter carried in the liquid when analyzing the total suspended solids (TSS) of a sample. The solids may include sugars, salts, and soluble BOD that may not be indicated by a TSS analysis. To determine the amount of dissolved solids, place a specific amount of liquid in a pre-weighed crucible, dry it completely on a hot plate and in an atmospheric oven, cool it, re-weigh, and calculate the difference.

Settleable solids (30-minute settling test)

This analysis mimics the solids settling activity in a final clarifier. To do it, place 1000 mL of mixed liquor in a 1000 mL graduated cylinder or settleometer. Wait 30 minutes, and then read the amount of settled solids. Using this test allows an operator to detect slow or fast settling, denitrification in a final clarifier (rising clumps of dark sludge), possible filamentous problems (bulking sludge), too high or low MLSS and other observations. By also doing the MLSS analysis, an operator can calculate a Sludge Volume Index – another indicator of the ratio of solids to volume that helps one estimate biomass health.

Sludge level in clarifier

This is the simplest solids test of all and can provide advanced warning of potential problems. A “Sludge Judge” or sludge core sampler is lowered into the clarifier at about the midway point of the cone. When the sampler is brought back to the surface, a check valve on the bottom closes. These sampling devices usually have markings every 12 inches to allow you to measure the sludge layers in the clear plastic tube. Doing this simple procedure will let you know whether denitrification is taking place in the final clarifier, the MLSS are too high, the RAS rate is too low or high, or there is a filamentous bulking problem, among many other process control indicators.

Biochemical oxygen demand

Biochemical oxygen demand includes several different analyses for determining organic loading to the wastewater facility and the amount of organic waste in the effluent. Because it takes five days to complete, it is difficult to make process adjustments using the results. It is essential, however, for determining loading to the plant from sidestreams, septage waste, and industrial contributors. It is also a requirement on all Minnesota Discharge Monitoring Reports.

The analysis is the permit-required test that shows the amount of oxygen used during a specific time (5 days) at a specific temperature (20°C) by the microorganisms in a sample. Knowing the BOD allows you to stabilize the organic substances in the sample. It is the most accurate indicator of the “strength” or amount of organic waste in influent and effluent wastewater.

Total BOD (usually just called BOD) contains both carbonaceous (carbon-based) and nitrogenous (nitrogen-based) BOD. The carbon portion is most available for food for the organisms. To do the analysis, place a known amount of sample into a 300 mL BOD bottle along with additional nutrients, take a dissolved oxygen (DO) reading, record it, and then place the sample into a 20°C incubator for five days. After the incubation period, take another DO reading, Subtract the second DO reading from the first and calculate the BOD in mg/L.

If you nitrify and denitrify, you can lower your effluent Total BOD, because the NBOD is reduced

Carbonaceous BOD (CBOD) is the BOD analysis with a chemical compound added to inhibit the nitrogenous BOD. The CBOD fraction is more available as food to the microorganisms in wastewater facilities than the nitrogenous portion (NBOD). Many facilities in Minnesota have a CBOD limit in their permit.

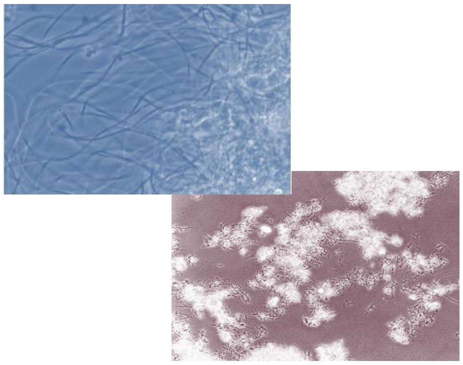


Figure 29: Filamentous and foaming organisms

Nitrogenous BOD (NBOD) has no separate analysis; the analyst just subtracts the CBOD result from the Total BOD result.

Soluble BOD (SBOD) is the BOD analysis of the sample after it is filtered, and the solids removed. SBOD can indicate the presence of dissolved sugars, alcohols, or other dissolved substances that contribute to the loading. When compared to Total BOD, it can indicate the effectiveness of primary solids removal. It is an important analysis for systems with a primary clarifier as it gives a more accurate indication of the BOD that is actually available for the microorganisms after the solids are removed.

Microscopic examination

By using a microscope to examine mixed liquor suspended solids at least once per week and doing a microorganism ratio of each type observed, an operator can:

- determine the general health of the system
- estimate SRT
- check for an overabundance of filamentous organisms
- identify filamentous organisms
- check for toxic effects
- observe excess greases and oils

- observe Nocardia in foam
- make many other helpful observations

If possible, use a phase contrast microscope because the contrast allows the viewer to see with greater clarity. A microscope that has at least a 100X lens (provides 1000X magnification) is helpful, and essential for using oil immersion.

Helpful monitoring

- Oxidation-reduction potential (ORP)
- Alkalinity
- Soluble COD
- Volatile Fatty Acids

Figure 30: Monitoring that is helpful when doing biological nutrient removal

If you are struggling with filamentous organisms and wish to identify them yourself, purchase a gram stain kit and sign up for a class or request informational materials from the MPCA about filamentous identification.

If you suspect“slime” bulking problems, purchase a bottle of India ink at an office supply store, and follow the simple procedure on page 37 of this manual to see whether excess exocellular lipopolysaccharides are present surrounding the bacteria in mixed liquor floc particles. This presence of this condition indicates organisms are stressed because of insufficient nutrients (usually nitrogen), or overabundant organic acids that may be added by digester recycle streams or other anaerobic sources.

Oxidation-reduction potential (ORP)

Oxidation-reduction potential is a state of oxidation (gaining or losing oxygen molecules) that can be measured with a specialized probe and a common millivolt (mV) or pH meter placed on a millivolt setting in either positive or negative numbers. Since DO meters will only register to 0.0 mg/L, an operator will not be able to distinguish between anaerobic (0.0 mg/L) and anoxic (0.0-0.1 mg/L) conditions using a DO meter. An ORP probe and mV meter can serve this function. Although each facility may be a little different, your readings should be similar in range to those in Table 3.

Many facilities have placed ORP probes in-line for greater selector zone control. The only other equipment required is a field pH/Mv meter. By keeping the ORP at the appropriate optimal levels for different zones, the operator maintains much more ability to monitor and control the BNR process.

Table 3: Desired conditions and millivolt meter readings by zone

Zone	Desired conditions	mV reading
Aerobic (oxic)	Oxygen present	+50 to +200 mV
Anoxic	Little or no oxygen, just nitrates	+50 to -200 mV
Anaerobic	No nitrates, no oxygen present	-300 mV or lower

Alkalinity

Alkalinity is the indicator of the acid-neutralizing capacity of water. It is not the same as pH; it is a precursor to a drop or rise in pH. The process of nitrification uses a large amount of alkalinity, which may then cause a harmful drop in the pH of mixed liquor.

While there are many “kit” tests for alkalinity, the actual analysis is very easy. Titrate a sample with a 0.1N sulfuric or hydrochloric acid solution to a pH of 4.5 and calculate to determine the total alkalinity in mg $CaCO_3$/L. An indicator solution may also be used if the operator does not have a pH meter available. If the alkalinity in the plant lowers to dangerous levels, such as 50 mg/L, the operator may have to add caustic solutions to keep the microorganisms healthy.

Chemical oxygen demand (COD)

The COD analysis is used to quickly estimate loading and demand since it can be completed in less than two hours. This analysis requires a spectrophotometer, a means to digest the sample, and a fume hood. The operator will need to compare BOD and COD results to establish estimates of BOD. Methods 5220 and 5220D (see *Standard Methods for the Examination of Water and Wastewater*) describe the general procedure, but some suppliers have developed mini-digestion units and easier analytical methods. The COD analysis may be used to calculate a COD: phosphorus ratio, which should be less than 40:1 for optimum BNR. One of the advantages to using COD over BOD is that is can be completed in much less time. Heavy metals or other toxic compounds may inhibit BOD, resulting in values lower than the true value. Also, unless nitrification is suppressed by chemical nitrification inhibitors (CBOD), nitrifying organisms in the sample may multiply and utilize oxygen, giving an inflated value.

Soluble COD gives an even more accurate estimate of the available food for the microorganisms. COD is broken down into two main divisions, biodegradable and nonbiodegradable soluble as indicated in the chart below. The nonbiodegradable soluble COD will pass through the treatment processes, and the nonbiodegradable particulate will be tied up in the sludge and wasted out of the system. The biodegradable COD portion consists of readily biodegradable soluble COD and slowly biodegradable particulate COD. The soluble readily biodegradable fraction plays an important role in biological phosphorus removal because phosphorus-removing microorganisms require it to sequester volatile fatty acids, their main source of energy. Studies show that as soluble readily biodegradable COD values in the influent increase, the release of phosphorus in the BNR system also increases. The method and spreadsheets for monitoring using soluble COD are located at: http://dnr.wi.gov/org/water/wm/ww/biophos/3fract.htm

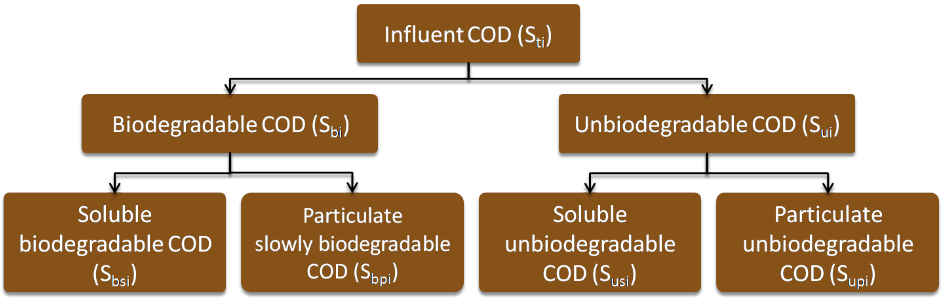


Figure 31: Types of COD in influent

Volatile acids

This analysis requires a centrifuge, distillation apparatus and a pH meter. Centrifuge the sample to separate the solids, distill it, and then titrate with a color indicator, a pH meter, or an automatic titrator. The distillation is somewhat time-consuming, but volatile acid content is an important factor in determining whether there is adequate food for the phosphorus-removing organisms. The optimal ratio of VA:P removed is 7-10 mg:1 mg.

Table 4: *Standard Methods for the Examination of Water and Wastewater* reference methods

Analyte	Method
Total Suspended Solids dried at 103-105° C	2540D
Total Solids dried at 103-105° C	2540B
Total Dissolved Solids dried at 180°C	2540C
Fixed and Volatile Solids Ignited at 550°C	2540E
5-Day Biochemical Oxygen Demand (BOD)	5210B
Chemical Oxygen Demand	5220 B, C, D
pH - Electrometric Method	4500-H^+B
Ammonia Nitrogen	
• Preliminary Distillation Step	4500-NH3 B
• Titrimetric Method	4500-NH3 C
• Ammonia-Selective Electrode Method	4500-NH3 D
• Spectrophotometric Phenate Method	4500-NH3 F
Nitrite Nitrogen Colorimetric Method	4500-$NO2^-$ B
Nitrate Nitrogen Cadmium Reduction Method	4500-$NO3^-$ E
Total Kjeldahl Nitrogen	
• Macro-Kjeldahl Method	4500-N_{org} B
• Micro-Kjeldahl Method	4500-N_{org} C
Volatile Fatty Acids – Distillation Method	5560 C
Alkalinity – Titration Method	2320 B

Evaluate your process

Table 5: Suggested daily process control calculations for optimum BNR

Solids Retention Time (SRT)	SRT affects BNR of nitrogen, phosphorus. SRT needs to be long enough to nitrify, but if it is too long, the GAO's will predominate over PAO's, affecting phosphorus removal. 5-12 days SRT are recommended.
Wasting rates	Wasting affects SRT, which in turn affects BNR. (See Solids Retention Time)
Return flow rates	Nitrate and DO in RAS affect nitrification, and too low return flow affects levels of PAOs in anaerobic and anoxic zones. Too low return flow may also cause denitrification in the final clarifier. The MLVSS recycle to the anaerobic zone directly affects phosphorus removal, since the volatile portion is the organic portion containing the microorganisms required for bio-P. Typical RAS rates are 1X the daily flow, but it depends on the influent volatile solids loading.
Hydraulic detention time (HDT) in anaerobic and anoxic zones	High or low flows will affect detention time in the anaerobic and anoxic selectors. BNR requires 1-2 hours of DT in anaerobic zones, and typically 2-3 hours in anoxic zone (depending on the type of system) to ensure that the readily biodegradable soluble COD ferments to form VFAs. Refer to the design manual for your facility for HDT information.
Influent loading of ammonia nitrogen and organic nitrogen (Kjeldahl)	High TKN with high NH3 may indicated the inability of the organisms to nitrify, and high TKN with low NH3 (high organic portion) may inability of the microorganisms to break down certain organic compounds.
Influent loading of total phosphorus	As with other parameters, the influent loading should not exceed the design loading for total phosphorus. Typical municipal phosphorus influent is 5-9 mg/L; industrial may be much higher.
Soluble COD influent loading	The higher the biodegradable available soluble COD, the higher the release of phosphorus.
Sidestream loading of BOD/COD, Soluble COD, Ammonia Nitrogen, Nitrate, Sulfides, and/or Total Phosphorus	Consider all sidestreams to be influent loading; add them to the calculations for total loading to the system. If sidestream loadings are a problem, action should be taken to either find alternative addition points for the recycle, switch to a different type of process that contributes a recycle with much lower loading rates, or treat the recycle to remove contaminants (such as ferric chloride to remove the phosphorus).
Ratios – BOD: N (10:1), BOD: P (20:1), COD: P (, Soluble COD: P, VFA: P	By monitoring these ratios, the operator has unique control over the system. If nutrients are deficient, additional nutrient may be added, such as molasses or acetic acid.
Food to Microorganism Ratio (F:M)	F:M is related to wasting rates, which can be controlled, and influent BOD/COD rates, which usually cannot be controlled. Optimal F:M depends on the type of wastewater process. Too low F:M does not provide the BOD/COD necessary to optimum P removal, and too high F:M may let the CBOD, NBOD, ammonia nitrogen and phosphorus pass through the system without treatment, as there will not be enough microorganisms to break it down.

Tweak for optimum performance

By creating charts you can see trends and predict problems before they happen. You can also find your optimal parameters by making comparison charts that depict more than one data stream such as: effluent phosphorus vs. MLSS; DO ranges in selectors vs. effluent total P; temperature data vs. nitrification rates, etc.

India ink stain for exocellular lipopolysaccharides

- Obtain a sample of mixed liquor from the end of the aeration basin, or, in an SBR, from the end of the react cycle.
- Mix the sample well, and, place a drop or two onto a clean, grease-free microscope slide.
- Add a small drop of water-soluble India ink. This can be purchased from an art supply or office supply store.
- Cover the sample with a cover slip. Be sure to remove excess fluid from around the slide by touching a piece of paper towel to the edge of the slide to draw off the excess.
- Place a drop of immersion oil directly on top of the cover slip and view the slide with the 100X oil immersion lens.
- Observe the sample with brightfield and the maximum light possible. Do not use the phase contract condenser.
- The slime (exocellular lipopolysaccharides) around the bacterial cells will prevent the India ink particles from penetrating the floc. If excess lipopolysaccharide is present, the floc will appear white. If it is not present, it will appear black.

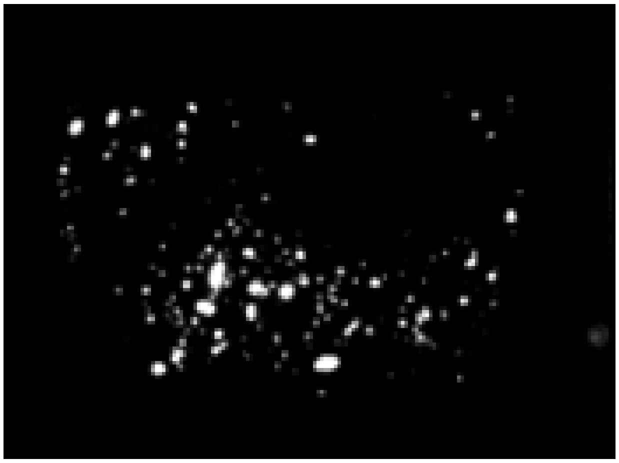


Table 6: Process control parameters

[Essential for optimum bio-p removal] [Essential for optimum nitrification/denitrification]

Analysis	**Sampling Sites**	**Suggested Frequency**	**Optimal Parameters**
Dissolved Oxygen (DO)	Anaerobic, anoxic, oxic zones, end of aeration basins	Constant or at least 2 X per day	0.0 in anaerobic zone, 0.1 in anoxic zone, 0.5-2.0 in oxic (lower at end)
Oxidation Reduction Potential (ORP)	Anaerobic, anoxic, oxic zones	Constant or at least 2 X per day	See Table 3 page 35
Temperature	Anaerobic, anoxic, oxic zones	Daily	20° C is optimal
pH	Influent, effluent, end of aeration basins	Daily	6.8-9.0 SU (above 7.4 w/high NH_3 is toxic)
Orthophosphate (or Total Phosphorus)	Influent, effluent, all selector zones; sidestreams*	At least 1 X per day	< 10 mg/L influent ; permit limit, effl.; sidestreams – low as possible
Ammonia nitrogen	Influent, effluent, all selector zones; sidestreams*	Daily	12-50 mg/L, influent; permit limit, effluent
Nitrates/Nitrites	All selector zones, RAS, effluent	Daily	0 in effluent; RAS <1% of infl. or less
Mixed liquor suspended solids	End of aeration basins	Daily	Optimal for YOUR plant
Effluent suspended solids	Effluent 24-hour composite or grab sample	Daily	Permit limit, the lower the better for P removal
RAS/WAS suspended solids	RAS/WAS line	Daily	1.5 – 2.0 X MLSS
Sidestream*(suspended solids, BOD, N, NO_3, P)	All sidestreams going back into system	When sidestreams are being pumped back	As low as possible
30-Minute settling test	End of aeration basins	Daily	100-400 mL; optimum SVI = 100; no denitrification
Solids in clarifiers (Sludge Judge)	Primary and final clarifiers	Daily	0.5-3 feet, depends on RAS rate; no signs of denitrification
Microscopic Analysis of Mixed Liquor	End of aeration basins or final clarifier solids	Weekly; more frequently if something is abnormal in plant	Good ratio of all beneficial microorganisms and protozoa; no polyliposaccarides /excess filamentous growth
Volatile Solids of Mixed Liquor	End of aeration basins	Weekly	75% of Total Solids
Biochemical Oxygen Demand	Influent, effluent 24-hour composite	As per permit	As per permit & optimum BOD:P ratio
Chemical Oxygen Demand (Biodegradable soluble COD)	Influent (primary effluent)	Daily	COD >25 mg/L; COD:P > 40; soluble available COD:P >15
Total Kjeldahl Nitrogen	Influent (primary effluent)	Weekly	20-86 mg/L typical; organic nitrogen approx. 40% of TKN
Volatile Fatty Acids	Influent (primary effluent)	Daily	7-10 mg/mg P removed
Sulfates	Influent (primary effluent); septage intake	When plant is experiencing problems	>500 mg/L inhibits nitrification

*Sidestreams include filter backwash, centrifuge centrate, anaerobic digester supernatant, aerobic digester decant, filter press or gravity belt thickener filtrate, DAF subnatant, composting leachate, incinerator scrubber water, and sludge drying or reed bed underdrains.

Calculations for biological nitrogen and phosphorus removal

1. The BOD of influent wastewater is 275 mg/L and the influent phosphorus is 12 mg/L. A ratio of >20:1 is needed. Will the wastewater be amenable to biological phosphorus removal?

$$\text{Ratio} = \frac{\text{Influent BOD5}}{\text{Influent P}} = \frac{275\ \text{mg/L}}{12\ \text{mg/L}} = 23:1$$

   Since the ratio is greater than 20:1, YES, it is amenable to biological phosphorus removal.

2. Determine the hydraulic retention time, in hours, in a 0.050 MG anaerobic selector if the influent flow is 1.25 MGD.

$$\text{Detention Time} = \frac{\text{Volume}}{\text{Flow}} = \frac{0.050\ \text{MG}}{1.25\ \text{MGD}} = \left.\underline{0.04\ \text{days}}\,\right|\,\frac{24\ \text{hrs}}{1\ \text{day}} = 0.96\ \text{(or 1) hour}$$

3. Given the following information, what is the solids retention time (SRT) in this biological phosphorus removal plant?

   - Total volume of the anoxic, anaerobic and aeration basins = 475,000 gallons
   - Mixed Liquor Suspended Solids = 2200 mg/L
   - Wasting rate = 12,000 gallons/day
   - WAS concentration = 4000 mg/L

$$\text{Solids retention time (days)} = \frac{\text{Mass of solids in biological reactors (lbs)}}{\text{Mass of solids removed daily (lbs)}}$$

$$= \frac{[\text{Total volume (MG) x MLSS (mg/L) x 8.34 lb/gal}]}{[\text{WAS rate (MGD) x WAS concentration x 8.34 lb/gal}]}$$

$$= \frac{0.475\ \text{MG x 2200 mg/L x 8.34}}{0.012\ \text{MGD x 4000 mg/L x 8.34}}$$

$$= 22\ \text{days}$$

4. Given the following data, calculate the phosphorus load from the sidestream (decant) from a sludge storage tank:

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

   Phosphorus load (lbs) = Decant flow (MG) x phosphorus concentration (mg/L) x 8.34 lbs/gal

   = 0.075 MG x 35 mg/L x 8.34 lbs/gal

   = 21.89 or 22 lbs/day

5. Determine the hydraulic retention time in a 150,000-gallon anaerobic selector if the influent flow is 1.15 MGD and the return activated sludge flow is 0.60 MGD.

$$\text{Detention time} = \frac{\text{Volume of tank}}{\text{Flow}}$$

$$= \frac{0.150\ \text{MG}}{1.15\ \text{MGD} + 0.6\ \text{MGD}} = \frac{0.857\ \text{days}}{}\,\Big|\,\frac{24\ \text{hours}}{1\ \text{day}} = 2.1\ \text{hrs}$$

6. Given the following information, find the solids retention time (SRT) in a biological phosphorus removal plant:

- Volume of anaerobic selector = 45,000 gallons
- Volume of anoxic selector = 55,000 gallons
- Volume of aeration basins = 500,m000 gallons
- Mixed liquor suspended solids (MLSS) = 3400 mg/L
- WAS concentration = 5,000 mg/L

$$\text{SRT (days)} = \frac{\text{Mass of solids in biological reactors (lbs)}}{\text{Solids removed daily (lbs)}}$$

$$= \frac{[\text{Tank volumes (MG)} \ \text{x} \ \text{MLSS (mg/L)} \ \text{x} \ 8.34\ \text{lbs/gal}]}{[\text{WAS rate (MGD)} \ \text{x} \ 5{,}000\ \text{mg/L} \ \text{x} \ 8.34\ \text{lbs/gal}]}$$

$$= \frac{[(0.45\ \text{MG} + 0.055\ \text{MG} + 0.5\ \text{MG}) \ \text{x} \ 3400\ \text{mg/L} \ \text{x} \ 8.35\ \text{lbs/gal}]}{[0{,}02\ \text{MGD} \ \text{x} \ 5{,}000\ \text{mg/L} \ \text{x} \ 8.34\ \text{lbs/gal}]}$$

$$= 20\ \text{days}$$

7. Given the following data, find the total phosphorus loading into a treatment plant.

- Influent flow = 0.24 MGD
- Influent P = 6 mg/L
- Sludge storage tank decant flow = 10,000 gpd
- Sludge storage tank decant phosphorus = 48 mg/L
- Belt press filtrate flow = 12,000 gpd
- Belt press filtrate phosphorus = 20 mg/L

Total loading (lbs) = [Influent flow (MGD) x Influent P (mg/L) x 8.34 lbs/gal] + Lbs P from sidestreams

(P from sidestreams = [Storage tank decant flow (MGD) x Storage tank P (mg/L) x 8.34 lbs/gal] +
[Filtrate flow (MGD) x Filtrate P (mg/L) x 8.34 lbs/gal])

Total loading = [0.24 MGD x 6 mg/L x 8.34 lbs/gal] + [0.01 MGD x 48 mg/L x 8.34 lbs/gal] +
[0.012 MGD x 20 mg/L x 8.34 lbs/gal]

= 12 lbs + 4 lbs + 2 lbs = 18 lbs

8. Total phosphorus influent to a WWTP is 9.39 mg/L. The effluent has a total phosphorus content of 0.91 mg/L. What is the percent removal of phosphorus by this facility?

   (9.39 mg/L – 0.91 mg/L) ÷ 9.39 mg/L = (0.903 ÷ 100%) = 90.3%

9. An orthophosphate test result of a WWTP effluent is 0.81 mg/L. After analyzing comparison tests for orthophosphate vs. total phosphorus, the laboratory discovered that the orthophosphate is usually 76% of the total phosphorus. Using this multiplier, what is the estimate of the total phosphorus of the plant effluent?

   0.81 mg/L ÷ (76%/100) = 1.07 mg/L

10. A dairy contributed 72,800 gallons of waste on July 15 to the influent of a city's wastewater treatment plant. The total phosphorus content of the waste was 23.8 mg/L. If the city surcharges the industry $10 per pound over a baseline of 5 mg/L, what is the industry surcharge for July 15?

    0.0728 MGD x 8.34 lb/gal x (23.8 mg/L – 5 mg/L) = 11.4 pounds

    11.4 pounds x $10 per pound = $114.14 for July 15

11. If the daily influent Total Kjeldahl Nitrogen (TKN) is 75.5 mg/L, and the ammonia nitrogen is 31.1 mg/L, what is the organic nitrogen content in mg/L? What percentage of the TKN the ammonia nitrogen?

    75.5 mg/L – 31.1 mg/L = 44.4 mg/L

    31.1 mg/L ÷ 75.5 mg/L = 0.4119 x 100% = 41.2%

12. If Total 5-day BOD results for a plant influent are 410 mg/L, and the CBOD results on the same sample are 311 mg/L, what is the Nitrogenous BOD (NBOD) estimated result?

    410 mg/L – 311 mg/L = 99 mg/L

13. After implementing phosphorus removal, biosolids production at a WWTP rose approximately 20% when using only biological phosphorus removal. When using only chemical phosphorus removal, the facility produces 31% more biosolids than it had before nutrient removal. Biosolids production was originally 30,000 pounds per day, and the cost of production and disposal was $0.75 per pound. Chemicals added $250.00 per day to the cost of chemical removal. What is the total cost savings of using biological phosphorus removal over chemical removal?

    Biological removal: 30,000 pounds/day x 0.20 = 6,000 pounds

    6,000 pounds x $0.75/pound = $4500.00

    Chemical removal: 30,000 pounds/day x 0.31 = 9,300 pounds

    9,300 pounds x $0.75/pounds = $6975.00 + $250.00 chemical costs = $7225.00

    $7225.00 – $4500.00 = $2725.00/day savings using biological vs. phosphorus removal

14. Given the following data, calculate the wasting rate in gallons per day to maintain a Solids Retention Time (SRT) of 3 days. If the waste pump operates at 300 gallons per minute, how many hours will it take to waste this amount?

- Average weekly MLSS: 3282 mg/L
- WAS suspended solids: 7580 mg/L
- Basin volume: 1.50 MG

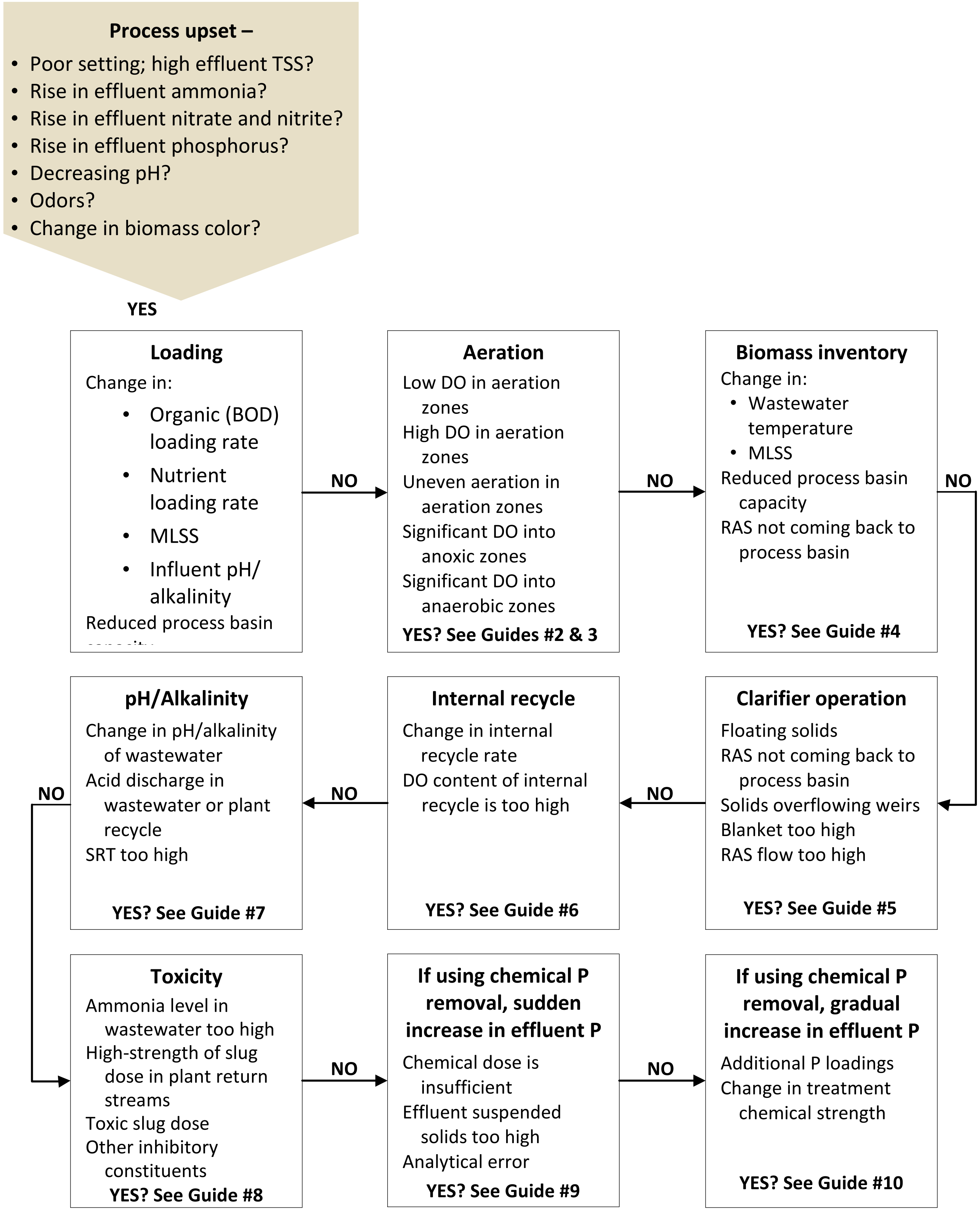
$$\frac{(3282\text{ mg/L} \times 1.5\text{ MG})}{(7580\text{ mg/L} \times 3\text{ days})} = 0.2165\text{ MGD or }216{,}500\text{ gal/day}$$

$$\frac{216{,}500\text{ gallons}}{300\text{ gallons/minute}} = \left.\underline{722\text{ min}}\,\right|\,\frac{1\text{ hour}}{60\text{ min}} = 12\text{ hours}$$

Table 7: Possible sources of nutrients and nutrient removal problems

Nitrogen	• Recycle streams • Cooling towers • Fertilizer • Meth labs	• Agriculture wastes • Septage and port-a-potty wastes • Cold storm water runoff
Phosphorus	• Recycle streams • Dairy wastes • Food industries • Fertilizer • Meth labs • Photography labs • Plating industries	• Circuit board manufacturers • Agriculture wastes • Septage, port-a-potty wastes • Car and truck washes • Storm water with high organics • Soda bottling industries
Toxics	• Water softening • High chloride food industries • Truck washes • Heavy metals from industries • Cleaners/disinfectants • Wood weatherproofing treatments • Anti-freeze (port-a-potty treatments)	• High sulfide wastes (septage, industrial) • Storm water with petroleum, chlorides, other toxics • Pharmaceutical industries • Paint and solvents • Hide tanning
High solids	• Storm water runoff • Port-a-potty waste • Septage	• Sewer cleaning • High solids recycle streams

Optimization and Troubleshooting Guides



Process upset –
- Poor setting; high effluent TSS?
- Rise in effluent ammonia?
- Rise in effluent nitrate and nitrite?
- Rise in effluent phosphorus?
- Decreasing pH?
- Odors?
- Change in biomass color?

Loading
Change in:
- Organic (BOD) loading rate
- Nutrient loading rate
- MLSS
- Influent pH/ alkalinity

Reduced process basin

Aeration
Low DO in aeration zones
High DO in aeration zones
Uneven aeration in aeration zones
Significant DO into anoxic zones
Significant DO into anaerobic zones
YES? See Guides #2 & 3

Biomass inventory
Change in:
- Wastewater temperature
- MLSS

Reduced process basin capacity
RAS not coming back to process basin
YES? See Guide #4

Clarifier operation
Floating solids
RAS not coming back to process basin
Solids overflowing weirs
Blanket too high
RAS flow too high
YES? See Guide #5

Internal recycle
Change in internal recycle rate
DO content of internal recycle is too high
YES? See Guide #6

pH/Alkalinity
Change in pH/alkalinity of wastewater
Acid discharge in wastewater or plant recycle
SRT too high
YES? See Guide #7

Toxicity
Ammonia level in wastewater too high
High-strength of slug dose in plant return streams
Toxic slug dose
Other inhibitory constituents
YES? See Guide #8

If using chemical P removal, sudden increase in effluent P
Chemical dose is insufficient
Effluent suspended solids too high
Analytical error
YES? See Guide #9

If using chemical P removal, gradual increase in effluent P
Additional P loadings
Change in treatment chemical strength
YES? See Guide #10

Troubleshooting guide from "Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants," WEF Manual of Practice No. 29

Guide #1: Loadings

Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #1
1 • Raw wastewater odor • Dark color in aeration zone • Higher effluent NH_3-N, TKN or TP than normal	Excessive loading of BOD or TKN	Check NO_2 + NO_3-N at end of process before clarification for nitrification performance	
		If activated sludge, check DO in aeration zone	If activated sludge with diffused aeration/mixing, see OTG #2 If activated sludge with mechanical aeration/mixing, see OTG #3
		• If rotating biological contactor (RBC), check DO in first or second compartment • If trickling filter (TrF), check DO in trickling filter effluent	If RBC or TrF, try to increase aeration as short-term solution, if possible. Also see 1^a below
		1^aCheck BOD and TKN concentrations in influent to BNR process	Look at plant operations to see whether sidestreams from solids handling are causing periodically high loads and adjust operations to even out BOD and TKN loadings to process
		Check BOD and TKN concentrations in influent to plant	Check for and discourage discharges to collection system that are causing unusually high strength in the influent wastewater
	Effective capacity of process has been reduced	Check for grit deposits at bottom of basins	If activated sludge, increase MLSS to maintain SRT. Clean out accumulated deposits.
		Observe mixing and aeration patterns	If activated sludge with diffused aeration/mixing, see OGT #2 If activated sludge with mechanical aeration/mixing, see OTG #3
		If attached growth, look for excessive growth or debris that hinders aeration or airflow and causes short	Increase sloughing by flooding, increasing recirculation rate, flushing with hose, etc., as applicable.

	Observations/indicator	**Probable cause**	**Check/monitor**	**Solutions – Guide #1**
			circuiting	For TrF, clean out debris, restore airflow, consider increased recirculation rate. For other attached growth, distribute loading more evenly
2	• Pin floc in secondary clarifier effluent • High SVI • Sometimes dark tan foam on aeration basin • Higher effluent TP than normal if underloading of process occurs	Underloading of process (lower flow, BOD or TKN than design values) causing secondary release of nutrients	Compare actual flow, BOD and TKN values to design values	
			If multiple trains are in service, calculate loadings if fewer trains are in service	If calculated loadings are within design values with fewer trains in service, decrease number of trains in service
			If activated sludge, check MLSS and WAS solids concentrations and WAS flowrate and calculate SRT	If activated sludge, lower MLSS concentration to lower SRT and consider lowering RAS rate
		Nocardia-type microorganisms are favored by underloaded condition, influent oil/ grease concentration or plant design	Amount of fats, oils and greases	Eliminate the grease at the source or in pretreatment
			Calculate actual SRT	Keep the Solids Retention Time short (waste more sludge)
3	• Loading appears to be uneven (odors, MLSS color, and DO) • MLSS concentrations or DO different in different trains • Higher effluent NH_3-N or TKN than normal	Unequal flow distribution	Check flow of process influent to each train. Check NH_3-N, NO_2 $^{+}$ NO_3-N at end of process before clarification	Adjust flow-splitting devices to provide equal flow to same-sized trains or provide equal loadings to different-sized trains
		Unequal RAS distribution	If activated sludge and RAS enters separately, check RAS flow to each train	Adjust flow-splitting devices on RAS to provide equal flow to same-sized trains or provide equal loadings to different sized trains
		Unequal MLSS distribution	If process influent and RAS mix and then are split, check for good mixing and check flow to each train	Increase mixing if poor missing is observed before flow distribution. Adjust MLSS flow-splitting devices to provide equal flow to same sized trains or provide equal loadings to different-sized trains

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #1
4	• Dark diluted color of MLSS • Sometimes white, sudsy foam in aeration zone • Higher effluent NH_3-N or TKN than normal	MLSS is lower than desired because of excessive wasting	Check MLSS and DO and check NH_3-N, NO_2^{+} NO_3-N at end of process before clarification	If MLSS is low, DO in aeration zones is high, NH_3-N is high and NO_2^{+} NO_3-N is low, decrease wasting to allow MLSS to increase for an SRT adequate for nitrification to occur
5	• Low influent pH or low alkalinity • Higher effluent NH_3-N or TKN than normal	Low alkalinity in potable water combined with decomposition of wastewater in collection system during warm weather	Check influent pH and alkalinity	Decrease SRT by reducing MLSS through increase wasting if nitrification is occurring adequately or if nitrification is not desired Add alkalinity through chemical addition
		Acidic discharge(s) to collection system	Check influent pH, alkalinity and other parameters that could identify source of acidic discharge(s)	Identify and eliminate source or acidic discharge(s). For short-term solution
6	Higher effluent NH_3-N concentration	Higher BOD or TKN concentration in influent wastewater	Check BOD and TKN concentrations in influent to BNR process	Look at plant operations to see whether sidestreams from solids handling are causing periodically high loads and adjust operations to even out BOD and TKN loading to process
			Check BOD and TKN concentrations in plant influent	Check for and discourage discharges to collection system that are causing unusually high NH_3-N or BOD in the influent wastewater Check SRT and DO in process; adjust high if possible See OTG #s 2, 3 and 4
		Inhibition of nitrification	Check pH profile through process, DO in aeration zones and toxicity	For process adjustments, see OTG #7 For toxicity, see OTG #8
7	Higher effluent NO_2+NO_3 concentration	BOD/TKN ratio has changed	Look at plant operations to see whether sidestreams from solids handling are causing periodically high loads and adjust operations to reduce or even out BOD and TKN loadings to process	

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #1
7	*Continued*		Check BOD and TKN concentrations in influent to plant	If BOD/TKN is low, there may be insufficient BOD for denitrification in anoxic zones
			High TKN in influent	Check for and discourage discharges to collection system that are causing unusually high TKN
			Low BOD in influent	Add carbon source, such as methanol, to increase denitrification
		Inhibition of denitrification	Check NO_2+NO_3, DO and/or ORP profiles through process	Optimize the anoxic conditions in anoxic zones See OTG #S 2 or 3 for controlling aeration and OTG #6 for controlling internal recycle
8	Higher effluent TP concentration	BOD/TP ratio has changed	Check BOD, soluble BOD, TP and orthophosphorus in influent to BNR process	Look at plant operations to see whether sidestreams from solids handling are causing periodically high loads and adjust operations to reduce or even out TP loadings to process
			Check BOD, SBOD, TP and orthophosphorus in plant influent	If BOD/TP or SBOD/orthophosphorus is low, there may be insufficient VFAs for biophosphorus removal
			High TP in influent	Check for and discourage discharges to collection system that are causing unusually high TP
			Low soluble BOD (low VFAs) in fermentation zone	Add VFAs, such as acetic acid, to fermentation zone to increase biophosphorus removal
			Insufficient soluble BOD (VFAs) and additional VFAs unavailable	Use chemical phosphorus removal on short-term basis or, it this is continuing situation, use chemicals and recalculate SRT and wasting based on higher inorganic content of MLSS resulting from chemical solids production

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #1
8	*Continued*	Inhibition of phosphorus release in fermentation zone	Check orthophosphorus, NO_2+NO_3, NH_3-N, DO and/or ORP profiles through process; observe mixing in fermentation zone	Optimize the anaerobic conditions in fermentation zone and ensure there is no short-circuiting See OTG2 or #3 for controlling aeration and OTG #5 for controlling RAS rate. Increase fermentation zone volume, if possible
		Inhibition of biological phosphorus uptake	Check orthophosphorus, DO profiles through process Observe mixing in aerobic zone(s) Check aerobic HRT	Ensure there is sufficient HRT and no short-circuiting; see OTG #2 or #3 for controlling aeration Install baffling, if needed, to block strong currents from inlet to outlet of aeration zones
			Check influent VFA and VFA, orthophosphorus profiles through process	If shock load of influent VFA occurs, excessive phosphorus release in fermentation zone may exceed biological phosphorus uptake in the aerobic zone(s) Eliminate excess VFA discharge or equalize VFA load
			Check pH, temperature and microorganism population for glycogen accumulating organisms	If other causes of low biological phosphorus uptake have been eliminated from consideration, the treatment plant conditions (low pH, high temperature, etc.) may favor GAOs over phosphorus-accumulating organisms. Consider pH adjustment or chemical phosphorus removal
9	Odors in fermentation zone	Underloading of process is causing excessive detention time	Check detention time and ORP in fermentation zone	If possible, decrease volume of fermentation zone (e.g., decrease number of basins in service or lower operating water level) Increase RAS flow rate to return more NO_2+NO_3-N

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #1
10	Odors in anoxic zones	Underloading of process is causing excessive detention time	Check detention time and ORP in anoxic zones	If possible, decrease volume of anoxic zone Add some DO to beginning of anoxic zone Increase internal recycle to return more NO_2+NO_3-N and DO

Guide #2: Aeration/mixing – diffused aeration

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #2
1	Low DO in aeration zones	Poor oxygen transfer in aerations zones	Check for diffuser problems	See 5 & 6 below
		Insufficient aeration	Check airflow versus calculated airflow for loadings	Increase airflow to aeration zones until DO is approximately 2.0 mg/L
			Check DO profile through process	If airflow per diffuser is too high and additional aeration zones are available, put additional aeration zones in service
2	High DO in aeration zones	Flow, BOD and/or TKN are lower than design	Check airflow versus calculated airflow for loadings. Check DO profile through process	Decrease airflow to aeration zones until DO is approximately 2.0 mg/L. If airflow per diffuser is too low, take aeration zone(s) out of service to maintain at least the minimum recommended airflow per diffuser
			Compare actual flow, BOD and TKN to design values Calculate required airflow	If diffusers allow, reduce the amount of air added by periodically reducing or shutting off air (not more than 1.5-2hrs off to prevent odors) Use a combination of on time and either reduced airflow time or off time throughout the day to better match aeration to the oxygen demand
3	Significant DO into anoxic zones	Too much DO at internal recycle suction	Check DO in aeration zone where internal recycle originates	For activated sludge process with internal recycle, DO profile can be tapered for low DO at internal recycle suction
		Too much turbulence at influent	Observe turbulence or splashing at influent	Adjust basin levels, use baffles and/or modify inlet orts to minimize turbulence and introduction of DO to anoxic zones

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #2
4	Significant DO and/or NO_2+NO_3-N into fermentation zone	Too much DO returning with RAS	Check DO in RAS; check RAS concentration and flow	Reduce DO in aeration zone immediately upstream of clarifiers If clarifier operation allows, reduce RAS flow
		Too much NO_2+NO_3-N returning with RAS	Check NO_2+NO_3-N concentration in RAS Check RAS concentration and flow	If nitrification is not needed, reduce SRT to reduce NO_2+NO_3-N concentration going to clarifiers If clarifier operation allows, reduce RAS flow
		Too much turbulence at influent	Observe turbulence or splashing at influent	Adjust basin levels, use baffles and/or modify inlet ports to minimize turbulence and introduction of DO to anaerobic zones
5	Poor mixing pattern	Diffusers need cleaning or repair	Visual observation of mixing pattern	Bump or chemically clean in-place diffusers; take basin out of service and manually clean diffusers, replace broken diffusers or periodically replace all diffusers if beyond expected service life
		If blowoffs present, air is releasing through blowoffs	Check for excessive diffuser headloss or blowoff malfunction	Clean or replace diffusers (see above) and/or repair blowoff system
		Diffusers not installed at same elevation	Check that diffusers are installed level and at same elevation	Take basin out of service and adjust diffuser support systems and/or lateral so they are level and that diffusers are at the same elevation
6	No or too little turbulence	Too few blowers in operation	Check number of blowers in operation and control system	Increase number of blowers in operation or adjust controls to bring on more blowers if automatically controlled
		Blower malfunction	Compare airflow at each blower to its performance curve(s)	Diagnose and repair/replace malfunctioning parts Check setting of inlet air vanes and valves
		Dirty inlet filter	Check inlet air pressure between filter and blower	Replace inlet filters; clean filters if washable
		Valves need adjustment	Check airflow to basin	Adjust manual valves to better distribute air
		Aeration control system needs adjustment	Compare control parameter values to set point(s)	If insufficient air is provided under automatic operation, adjust controls to increase airflow when setpoints are maintained

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #2
6	*Continued*	Air rate too low for proper operation of diffusers	Compare airflow divided by number of diffusers to acceptable low value	Increase airflow to provide at least minimum recommended air-flow per diffuser
7	Excessive turbulence over entire basin	Too many blowers in operation	Check DO in aeration zones and number of blowers in operation	If DO is above desired levels, decrease airflow (Stay within range of recommended airflow per diffuser)
		Aeration control system needs adjustment	Compare control parameter values to setpoint(s)	If excess air is provided under automatic operation, adjust controls to decrease airflow when setpoints are maintained
		Air rate too high for proper operation of diffusers	Compare airflow divided by number of diffusers to acceptable high value	Decrease airflow to provide, at most, the maximum recommended airflow per diffuser

Guide #3: Aeration/mixing – mechanical

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #3
1	Low DO in aeration zones	Poor oxygen transfer in aeration zones	Check for aerator problems	See 5, 6a, 7 in this guide
		Insufficient aerators in service	Check total horsepower in service versus calculated horsepower	Increase number of aerators in service until DO is approximately 2.0 mg/L
			Check DO profile through process	If additional aeration zones are available, put them into service
2	High DO in aeration zones	Flow, BOD and/or TKN are lower than design	Check total horsepower in service versus calculated horsepower	Decrease level in basin to lower impeller submergence until DO is approximately 2.0 mg/L
			Check DO profile through process	If DO is still too high, take aerator out of service, use low speed, if two-speed aerators, or take an aeration zone out of service to maintain minimum impeller submergence
			Compare actual flow, BOD and TKN to design values	If aerators allow, periodically reduce the speed of aerator to reduce oxygen transfer but maintain mixing
			Calculate required aeration horsepower	If aerator is able to re-suspend solids, consider shutting off aerator(s) (not more than 1.5-2 hrs off to prevent odors)

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #3
				Use a combination of on time and either reduced speed time or off time throughout the day to better match aeration to the oxygen demand For large aerators, on-off operation may be too hard on gear reducers; consider soft-start of motors if on-off operation is used
3	Significant DO into anoxic zones	Too much DO at internal recycle suction	Check DO in aeration zone where internal recycle originates	For activated sludge process with internal recycle, locate internal recycle suction where DO is lowest and adjust submergence, as in #2 above If NO_2+NO_3-N concentration in effluent is low, reduce internal recycle rate
		Too much turbulence at influent	Observe turbulence or splashing at influent	Adjust basin levels, use baffles and/or modify inlet ports to minimize turbulence and introduction of DO to anoxic zones
4	Significant DO and/or NO_2+NO_3-N into fermentation zone	Too much DO returning with RAS	Check CO in RAs Check RAS concentration and flow	Reduce DO in aeration zone immediately upstream of clarifiers If clarifier operation allows, reduce RAS flow
		Too much NO_2+NO_3-N returning with RAS	Check NO_2+NO_3-N concentration in RAS Check RAS concentration and flow	If nitrification is not needed, reduce SRT to reduce NO_2+NO_3-N concentration going to clarifiers If clarifier operation allows, reduce RAS flow
		Too much turbulence at influent	Observe turbulence or splashing at influent	Adjust basin levels, use baffles and/or modify inlet ports to minimize turbulence and introduction of DO in anaerobic zones
5	Surging noise and waves in aeration zone	Water level too low for mechanical aerator impeller	Visual observation of waves in basin, surging noise Check impeller submergence level	Increase level in basin to provide recommended minimum impeller submergence Repair leaks in weirs or gates that allow water level to drop below desired level at low flows

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #3
5	*Continued*	Basin design prone to wave formation at aerator	Visual observation of waves reflecting off surfaces and creating standing wave	Adjust aerator speed or position, if possible, or modify basin using baffles to reduce the standing wave effect.
6	Motor overload	[a]Water level too low for mechanical aerator impeller	Visual observation of waves in basin, surging noise Check impeller submergence level	Increase level in basin to provide recommended minimum impeller submergence Repair leaks in weirs or gates that allow water level to drop below desired level at low flows
		Water level too high for mechanical aerator impeller	Check impeller submergence level, especially at peak flow	Decrease level in basin to limit impeller submergence to recommended maximum at peak flow
7	Vibration, reduced splashing, low DO	Impeller fouled with debris	Check for vibration, visual observation of impeller, visual observation of splash pattern	Take aerator out of service and remove debris from impeller
		Impeller fouled with ice		Take aerator out of service and remove ice from impeller, install manufacturer-approved shields that keep splash confined to basin and minimize ice formation

Guide#4: Biomass inventory

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #4
1	• Wastewater temperature is low, DO is higher • Higher effluent TKN than normal	Cold weather is slowing down biomass activity	Check wastewater temperature in process	Increase SRT to continue nitrification, if required If nitrification is not required during cold weather, adjust process to discourage nitrification (lower SRT, less air and lower MLSS and RAS flow rate)
2	• MLSS is low, dark diluted color of MLSS			
	• Higher effluent TKN than normal	MLSS is lower than desired due to excessive wasting	Check MLSS and DO and check NH_3-N and NO_2+NO_3-N at end or process before clarification	[a]Decrease wasting to allow MLSS to increase for an SRT adequate for nitrification to occur. Select a better time to obtain more consistent MLSS concentration and/or use moving average of seven or more days on which to bas wasting. Institute operational limits on the amount of wasting that can occur in one day.

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #4
	•	Aerobic zone is too small	Check actual SRT corresponding to stable operation versus SRT needed for nitrification	Add another train if train is available, enlarge aerobic zone or consider integrated fixed-film activated sludge system modification
	• If using a biophosphorus removal process without nitrification, higher effluent TP than normal	MLSS is low to inhibit nitrification and is too low for the temperature to maintain biophosphorus removal population	Check MLSS and DO and check orthophosphorus at end of process before clarification	Decrease wasting as in 2^a above. If nitrification occurs and there is insufficient aeration capacity to maintain stable operation, operate at low MLSS and implement chemical phosphorus removal until temperature increases to where biophosphorus population restored
3	• MLSS is high, pin floc in secondary clarifier effluent, high SVI, sometimes dark tan foam on aeration basin • Higher effluent TKN or TP than normal	High MLSS resulting from reduced wasting or seasonally higher temperatures	If multiple trains are in service, calculate loadings if fewer trains are in service	If calculated loadings are within design values with fewer trains in service, decrease number of trains in service
	•		Check MLSS and WAS solids concentrations and WAS flow rate and calculate SRT	Lower MLSS concentration to lower SRT and consider lowering RAS rate
	•	*Nocardia*-type microorganisms are favored by underloaded condition, influent oil and grease concentration or plant design	Amount of fats, oils and greases Calculate actual SRT	Eliminate the grease at the source or in pretreatment Keep the Solids Retention Time short (waste more sludge)

Guide #5: Clarifier operation

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #5
1	• Floating solids at surface, sometimes thick solids layer, possibly bulking solids • Higher effluent TSS or TP than normal	Denitrification in clarifier causing rising sludge	Check NO_2+NO_3-N and DO concentrations entering and leaving clarifiers	Increase RAS return rate and/or increase DO in clarifier influent
		RAS not being removed quickly enough	Monitor blanket height and check RAS rate and detention time in clarifiers Check orthophosphorus in RAS	[a]Verify that RAS is flowing normally from each clarifier Reduce solids detention time in clarifiers (lower blanket height, increase RAS rate and reduce number of clarifiers in service
		Excessive turbulence causing air bubbles in floc	Observe turbulence and presence of bubbles on floc from mixed liquor effluent	Reduce turbulence in aeration tank immediately upstream of clarifiers and reduce turbulence between aeration tank and clarifier inlet
		Filamentous organisms in mixed liquor causing bulking sludge	Check settleability and SVI	Minimize formation of filamentous organisms by adjusting conditions in process basin
2	• Solids overflowing clarifier weir • Higher effluent TSS and BOD than normal	RAS not being removed quickly enough	Monitor blanket height and check RAS rate	See 1[a] above
		Unequal flow distribution	Check flow to each clarifier	Adjust flow-splitting devices to provide equal flow to same-sized clarifiers or provide equal loadings to different-sized clarifiers
		Hydraulic overloading	Check surface overflow rates at peak flow	If available, place another clarifier in service Reduce surges to the clarifiers by controlling pumping stations in collection system and recycle streams from solids handling to equalize flows
		Turbulence from collection rake	Observe solids carryover when rake passes by	If possible, reduce rake travel speed

	Observations/indicator	Probable cause	Check/monitor	Solutions – OTG #5
3	• Pin floc • Higher effluent TSS than normal	Excessive turbulence upstream of clarifiers	Observe turbulence upstream and check DO in last aeration zone	Reduce aeration in aeration zone upstream of clarifiers Adjust flow-splitting devices or water levels to reduce turbulence upstream of clarifiers
		SRT too long	Calculate SRT (check MLSS and WAS solids concentration and WAS flow rate)	Reduce SRT by increasing sludge wasting Limit wasting increase to 10% higher for 2 times SRT to minimize unstable operation See OTG #4
		Short-circuiting in clarifier	Look for areas where floc carryover is heaviest Observe water level along effluent weir	Level weirs If possible, add or adjust baffling to reduce excessive velocities and density currents
		Upset resulting from loading or colloidal solids in sidestreams from solids handling	Measure TSS and turbidity in sidestreams from solids handling Check DO profile through process	Look at plant operations to see whether sidestreams from solids handling are causing periodically high loads and adjust operations to reduce colloidal solids and even out BOD and TKN loadings to process
		Toxicity	See OTG #8	See OTG #8
4	• Thin RAS • Higher effluent TP than normal	Plugging of sludge withdrawal	Check RAS concentration; observe sludge withdrawal equipment	Blackflush RAS collection system
		RAS return rate too high	Check RAS concentration	Reduce RAS return rate
5	• Turbid effluent • Higher effluent TSS or TKN than normal	Toxic or acid constituents in wastewater	See OTG #8	See OTG #8

Guide #6: Internal recycle

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #6
1	• If removing nitrogen through internal recycle, high NO_2+NO_3-N in effluent upstream of clarifiers • Higher effluent NO_2+NO_3-N than normal	Internal recycle flow rate is insufficient	Verify that internal recycle pumps are operating	If pumps are not operating, fix the problem and restore internal recycle flow
			Compare internal recycle flow rate versus design rate Look for clog in valve, line or pump	If pumps are operating and flow rate is lower than normal, unclog internal recycle system and restore internal recycle flow
		Internal recycle is returning too much DO	Check DO concentration in internal recycle	Reduce DO concentration in internal recycle See OTG #2 or #3, item 3
		Insufficient BOD for denitrification in anoxic zones	See OTG #1, item 7	See OTG #1, item 7
2	• DO in anoxic zone • Higher effluent NO_2+NO_3-N than normal	Internal recycle rate is too high for the loading to the process	Calculate internal recycle flow rate needed to achieve nitrogen removal and compare to actual rate	Lower internal recycle flow rate
3	Low DO in aeration zone with aeration system at maximum; average or high NH_3-N and low NO_2+NO_3-N in effluent upstream of clarifiers	Oxygen-limited condition in aeration zone is causing denitrification to occur simultaneously in aeration zone	Check profiles of DO, NH_3-N and low NO_2+NO_3-N through process	For short-term solution, consider discontinuing internal recycle flow if aeration zone is large enough to accomplish simultaneous nitrification/denitrification Increase aeration in aeration zone to reduce effluent NH_3-N, raise DO in aeration zone and allow resumption of internal recycle

Guide #7: pH/alkalinity

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #7
1	• pH is average in influent, but there is low pH in process effluent • Higher effluent TKN than normal		Check pH profile through process and effluent NH_3-N	
		SRT is too high	Check MLSS, WAS flow rate and WAS concentration and calculate SRT	Decrease SRT by reducing MLSS through increased wasting if nitrification is occurring adequately or if nitrification is not desired
		Insufficient alkalinity to maintain pH	Check effluent alkalinity	Add alkalinity through chemical addition Consider implementing anoxic zone if none exists to recover alkalinity through denitrification The anoxic zone can be created by shutting off aeration in the zone and ensuring good mixing through other means Internal recycle may be used to maximize alkalinity recovery
2	Low pH or alkalinity in influent to BNR process	Low pH or alkalinity entering plant	See OTG #1, item 5	See OTG #1, item 5
		Sidestreams in plant or acidic discharge in plant	Check pH and alkalinity in sidestreams	Look at plant operations to see whether sidestreams are causing low pH or alkalinity and adjust operations to even out pH and alkalinity entering process If acid is used in plan, consider neutralizing before returning to plant
		Insufficient alkalinity	Check effluent alkalinity	Add alkalinity through chemical addition

Guide #8: Toxicity

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #8
1	• Light color and/or high DO in aeration zones • Higher effluent TSS, TKN or TP than normal	Toxic load inhibited nitrification, leading to overaeration	[a]Check pH profile through process, DO in aeration zones, NH_3-N and NO_2+NO_3-N through process	Maintain as much biomass in areas unaffected by the toxic load through rerouting of TAS, reduction in aeration or mixing or isolation of basins to preserve biomass for reseeding
			Check raw wastewater samples and return streams from solids handling for toxic components	Identify and eliminate the source of toxic load
2	• Raw or chemical odor in process, pin floc in clarifier effluent or cloudy effluent • Higher effluent TSS or TKN than normal	Toxic load has affected the biomass	Take sample and refrigerate for later analysis – see 1[a] above Look for dead (inactive) microorganisms under the microscope to confirm	Maintain as much biomass in areas unaffected by the toxic load through rerouting of TAS, reduction in aeration or mixing or isolation of basins to preserve biomass for reseeding
			Check raw wastewater samples and return streams from solids handling for toxic components	Identify and eliminate the source of toxic load
3	• For attached-growth process, excessive sloughing with little or no biomass on media • Higher effluent TSS or TKN than normal	Toxic load has affected the biomass	Check raw wastewater samples and return streams from solids handling for toxic components Take sample and refrigerate for later analysis – see 1[a] above Look for dead (inactive) microorganisms under the microscope to confirm	Identify and eliminate the source of toxic load If recirculation is being used, turn off recirculation until toxic load has passed; restart recirculation after the load has passed to dilute any toxic residue

Guide #9: Sudden loss of chemical phosphorus removal

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #9
1	Pump failed	Power failure	Verify the pump has power	Provide power
		Mechanical failure	Check the manufacturer's troubleshooting information	Perform system checks and conduct maintenance as directed by the manufacturer
2	Chemical feed piping plugged	Chemical precipitates have formed in the piping, restricting flow	Verify that chemical is reaching the application point and potentially break the piping in search of the suspected restriction	If the chemical flow is restricted, the operations staff should attempt to remove the restriction or restricted piping Muriatic acid has reportedly been successful in dissolving the chemical buildup Contact your chemical distributor for additional advice Consider discontinuing carrier water that may be promoting the precipitate formation within the pipe
3	Slug loading	Additional loading from an unknown source	Monitor key industrial contributors	Work with industries to get their loadings under control and/or arrange appropriate compensation for treatment Apply penalties where appropriate
			Check sidestream contributions	Sidestreams should be treated carefully Contingencies may include adding chemical to the sidestreams, equalizing the flow and recycling sidestreams during periods of low loadings
			Consider growth of the service area	Increase dose rates, if possible Evaluate treatment capacity and expand where warranted
4	Loss of solids	Poor activated sludge treatment	Monitor effluent suspended solids	Improve effluent quality. See OTG #s 1, 4 & 5. Note: Because the effluent suspended solids will contain phosphorus, it will be considerably more difficult to meet a phosphorus effluent limit as effluent suspended solids get higher

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #9
5	Analytical error	Human error	Laboratory quality assurance/quality control	If laboratory data are in error, exclude the erroneous data from the data set for process control purposes; note the erroneous data, as required, if used for regulatory reporting

Guide#10: Gradual loss of chemical phosphorus removal

	Observations/indicator	Probable cause	Check/monitor	Solutions – Guide #10
1	Additional loadings	Industrial contributions	Monitor key industrial contributors	Work with industries to get their loadings under control and/or arrange appropriate compensation for treatment
		Sidestream contributions	Check sidestream contributions	Sidestreams should be treated carefully Contingencies may include adding chemical to the sidestreams, equalizing the flow and recycling sidestreams during periods of low loadings
2	Change in chemical strength	Inconsistent or low-grade chemical	Monitor chemical strength	Increase the dose rate when using weaker chemicals; decrease the dose rate when using stronger chemicals Require more consistent product from supplier

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Fax: 414-291-8841 Jenchie.Wang@SYMBIONTONLINE.com

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Chemical phosphorus removal

The term *metal salts* is used to describe iron or aluminum compounds that are used to precipitate phosphorus from wastewater. The most common chemicals used are ferric chloride ($FeCl_3$), ferrous chloride ($FeCl_2$), ferrous sulfate ($FeSO_4$), and aluminum sulfate, sometimes called alum ($Al_2(SO_4)_3$). Polymers added before final clarifiers are sometimes used as a supplement to enhance phosphorus removal through coagulation-improved settling. Lime and other carbonate compounds are sometimes used for both raising alkalinity levels and enhanced settling (see Table 8).

The simplified version of the chemical reaction of metal salts with phosphorus is that positively charged ferric or aluminum ions combine with negatively charged phosphate ions to form a precipitate, which settles out in a final clarifier or pond. Total phosphorus consists of soluble and particulate phosphorus. Metal salts primarily remove soluble phosphorus, which is measured as orthophosphate. Orthophosphate is sometimes called *reactive phosphate,* because it is the form of phosphorus that is reactive and most readily available to microorganisms and aquatic life.

Table 8: Characteristics of frequently used phosphorus removal chemicals

Iron solutions		
Ferric Chloride ($FeCl_3$)	**Ferrous Chloride ($FeCl_2$)**	**Ferrous Sulfate ($FeSO_4$)**
• Very acidic; may lower pH and alkalinity • Very corrosive • Produces fumes • Usually supplied as a 33-36% solution (11-13% iron) • Stains concrete & other materials • Can affect UV disinfection • May affect effluent chloride • Requires special storage, handling and feed equipment	• Acidic; may lower pH and alkalinity • Very corrosive • Produces fumes • Supplied as a 18-28% solution (8-13% iron) • Stains concrete & other materials • May affect effluent chloride • May affect UV disinfection • Requires special storage, handling and feed equipment	• Acidic; may lower pH and alkalinity • Very corrosive • Produces fumes • May contain impurities from steel processing if in raw form • Supplied as 23-25% solution (5-7% iron) • Stains concrete & other materials • Must be stored in heated area indoors • May affect UV disinfection • Requires special storage, handling and feed equipment

Other solutions		
Aluminum Sulfate (alum) $Al_2(SO_4)_3$	**Anionic Polymers**	**Lime**
• Acidic; may lower pH & alkalinity • Moderately corrosive • 49% aluminum sulfate (8-9 % aluminum) in liquid form • Available in dry form (powder); mix with water before use • Must be kept above freezing • Clear, light green or yellow liquid • Requires special storage, handling, and feed equipment	• Neutral; will not affect pH • Available in liquid or dry form • Mix with water before adding • Enhances coagulation to improve settling • Extremely slippery; may produce fall hazard on floors	• Alkaline; may raise pH • For pH adjustment and settling aid • Requires special storage, handling, and feed equipment

The final effluent total suspended solids should be minimized to ensure meeting a phosphorus limit, as they are usually are usually comprised of a high percentage of particulate phosphorus, which will add to the total phosphorus loading.

Storage and handling

Iron salts

Ferric chloride, ferric sulfate, and ferrous sulfate should be stored in tanks made of fiberglass-reinforced plastic, polyethylene, or saran-lined steel that is surrounded by a containment area with a volume equal to or exceeding the volume of the storage tank. Feed pumps should be compatible with the chemicals being used. Schedule 80 PVC piping and valves are commonly used. The storage temperature for each chemical is an important factor to remember.

Table 9: Chemical Information

Chemical compound	Ferric chloride	Aluminum sulfate (alum)
Formula	$FeCl_3$	$Al_2(SO_4)_3$
Molecular weight (g/mole)	162.5	594
Typical reaction with phosphorus	$FeCl_3 + PO_4^{-3} \rightarrow FePO_4\downarrow + 3Cl^-$	$Al_2(SO_4)_3 \bullet 14H_2O + 2\ PO_4^{-3} \rightarrow 2AlPO_4\downarrow + 3SO_4^{-2} + 14H_2O$
Mole ratio (Metal : P)	1 : 1	1 : 1
Weight ratio (Metal : P)	1.8 : 1	0.87 : 1
Mole ratio (Metal compound : P)	1 : 1	1 : 2
Weight ratio (Metal compound : P)	5.2 : 1	9.6 : 1
Commercial strength in solution	33-36%	48-50%
Percent of active ingredient (metal)	11-13%	8-9%
Specific gravity	1.37 @ 35%	1.335 @ 48.5%
Gallons of commercial-strength solution needed to remove 1 pound phosphorus (based on 1x stoichiometric reaction)	1.26 ~ 1.38	1.73 ~ 1.80

Chemical compound	Ferrous chloride	Ferrous sulfate
Formula	$FeCl_2$	$FeSO_4 \bullet 7H_2O$
Molecular weight (g/mole)	127	278
Typical reaction with phosphorus	$3FeCl_2 + 2PO_4^{-3} \rightarrow Fe_3(PO_4)_2\downarrow + 6Cl^-$	$3FeSO_4 \bullet 7H_2O + 2PO_4^{-3} \rightarrow Fe_3(PO_4)_2\downarrow + 3SO_4^{-2} + 7H_2O$
Mole ratio (Metal : P)	3 : 2	3 : 2
Weight ratio (Metal : P)	2.7 : 1	2.7 : 1
Mole ratio (Metal compound : P)	3 : 2	3 : 2
Weight ratio (Metal compound : P)	6.1 : 1	13.5 : 1
Commercial strength in solution	18-28%	23-25%
Percent of active ingredient (metal)	8-13%	5-7%
Specific gravity	1.40 @ 25%	1.140 @ 25%
Gallons of commercial-strength solution needed to remove 1 pound phosphorus (based on 1x stoichiometric reaction)	1.86 ~ 2.90	5.68 ~ 6.17

Courtesy of Jenchie Wang, Symbiont

Aluminum salts

Aluminum sulfate should be stored in tanks made of fiberglass-reinforced plastic, polyethylene, or 316 stainless steel. The tank must be surrounded with a containment area with a volume equal to or exceeding the volume of the storage tank. Feed pumps should be compatible with the chemicals being used. Schedule 80 PVC and stainless steel piping and valves are commonly used. The storage temperature of alum is critical, as it will easily crystallize.

Performance limiting factors

The choice of chemical and the amount of chemical used depends on many factors including:

- pH
- Alkalinity
- Colloidal solids
- Mixing of chemical and wastewater
- Competing chemical reactions in the wastewater
- Ultraviolet disinfection (ferric ions may interfere)
- Infiltration and inflow that changes the characteristics of the wastewater

The pH of the wastewater is important for optimal chemical reactions. Both ferric and alum compounds work best at a pH of 6.8-7.0, but will also work at a less optimal pH range of 6.0-8.5. Both alum and iron metals salts are acidic and will reduce alkalinity and pH. In low alkalinity wastewaters, adding metal salts could impair biological treatment – particularly nitrification – by consuming alkalinity.

Be careful not to overdose metal salts. Adding metal salts before the final clarifiers rather than ahead of the biological reactor may lessen the impact on the biological treatment; however, the mixing may not be optimal. Conduct jar or bench tests to find the optimal type of chemical, the correct amount to use, and how much mixing is needed. 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 and valves.

Points of addition for phosphorus removal chemicals

The points of addition of the chemical solutions and subsequent mixing are very important with the use of these metal solutions. Dosage points may be limited by lack of the availability of mixing, plant design, or type of treatment. See Table 10 for advantages and disadvantages of different points of addition.

Safety issues associated with phosphorus removal chemicals

- 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.
- Lime is very caustic and will produce fumes when mixed with water.
- The mixing of ferric chloride with sodium hypochlorite or the mixing of aluminum sulfate with sodium hypochlorite will cause an uncontrollable release of deadly chlorine gas.
- Mixing ferric chloride with aluminum sulfate will cause an exothermic reaction (releases heat) and a release of acid fumes.

Table 10: Advantages & disadvantages of different addition points

Addition point	**Advantages**	**Disadvantages**
Before primary clarification	• Enhanced suspended solids and BOD removal, reducing loading to aeration basins • Odor control • Convenience and mixing capability • Iron compounds may help to balance nutrients in anaerobic digester • May reduce struvite formation	• Greater chemical use • May require additional chemical added downstream • May result in higher biosolids production • Could affect nutrient ratio • May be competing reactions in the primary clarifier and secondary release in the biological treatment system
Secondary treatment (aeration basins and ponds)	• Good mixing in aerated basins or aerated ponds • Fe^{+2} is oxidized to Fe^{+3}, thus improving reaction with phosphate • Orthophosphates are readily available • Convenient	• Not recommended for attached growth systems (RBC, Trickling Filter) • May affect pH, alkalinity and nutrient ratio • Not recommended for stabilization ponds unless mixing is added (by boat prop or portable mixer) • Iron discolors structures and equipment
Before final clarification	• Efficient and high level of removal as most phosphorus is in the form of orthophosphate • Enhances final settling • Less interfering or competing reactions • Cost effective	• Inadequate mixing

Byproducts of chemical phosphorus removal

1. Vivianite, a hydrated iron phosphate, is a hard, dark crystal that can form in piping and valving when excess iron salts are added to what is required for phosphorus removal.
2. Up to 30% excess biosolids may be produced

Calculating chemical addition

If your chemical supplier or engineer is able to give you an idea of the amount to add as pounds of P to pounds of Fe or Al or a gallon:gallon ratio for phosphorus removal chemical addition, you will only be required to monitor the influent and effluent phosphorus levels and chemical pumping. However, the amount of phosphorus that your facility receives may fluctuate widely. Also, different lots or brands of chemicals may contain varying amount of active metal compounds. The most accurate way to conduct chemical phosphorus removal is by analyzing the influent phosphorus levels, along with any sidestreams that may affect the phosphorus level in the plant and using metal removal ratios to calculate the amount required to remove phosphorus to permit effluent levels.

Table 11: Weight ratios for commonly used metal salts

Metal salt	Weight ratio to P
Ferric Iron (Fe^{+3})	1.8 to 1
Ferrous Iron (Fe^{+2})	2.7 to 1
Aluminum	0.87 to 1

In the chemical reaction of phosphorus with a metal salt (in this case, ferric), a positively charged iron ion (+3) combines with a negatively charged phosphate ion (-3) to form the precipitate, iron phosphate. In this case, 1 mole of Fe will react with 1 mole of P, making the mole ratio 1:1. The weight of one mole of iron is 56 grams and the weight of one mole of phosphorus is 31 grams, so the weight ration of Fe^{+3} to P is 56 ÷ 31 = 1.8. This makes the Fe^{+3}:P ratio 1.8:1, meaning that it takes 1.8 pounds of ferric to remove 1 pound of phosphorus. See Table 11 for the weight ratios for the commonly used metal salts.

Calculating surcharges for phosphorus loading

Some industries and commercial establishments such as dairies, plating industries, food packaging, fertilizer manufacturers, or car washes, may contribute large amounts of phosphorus to the municipal waste streams. Some cities and villages implement surcharges based on the amount of phosphorus contributed over and above the background influent phosphorus levels. For instance, if a city has a normal influent total phosphorus level of 6 mg/L, and analyses of industrial wastes show that they are contributing 70 mg/L total phosphorus, a city may decide to apply a treatment surcharge per pound of phosphorus for anything that is contributed over the background amount. If an industry also had a flow of 75,000 gallons on that same day, and the city charged $2.09 per pound of phosphorus treated, the calculation would be:

1. Industry P mg/L – background P, mg/L = chargeable P, mg/L
   70 mg/L – 6 mg/L = 64 mg/L

2. Industry daily flow, MGD x 8.34 lbs/gallon x chargeable P mg/L = pounds chargeable P
   0.075 MGD x 8.34 lbs/gal. x 64 mg/L P = 40.03 pounds of chargeable total phosphorus

3. Pounds chargeable total phosphorus x surcharge amount per pound
   $2.09 x 40.03 pounds = $83.67 daily total phosphorus loading surcharge

Example calculation

The following is an example of using metal salt chemical data to calculate theoretically the amount of chemical metal salt solution to add in gallons per day to remove phosphorus.

Information for example calculation

- Influent flow to plant: 2.0 MGD
- Influent phosphorus: 8 mg/L (from a 24-hour composite sample)
- Ferric chloride solution is used
- Specific gravity of solution: 1.40
- Percent metal (Fe) in solution: 12.5%
- Metal removal ratio (weight basis): 1.8:1.0 ($Fe+^3$:P)

Step 1: Determine the amount of influent phosphorus to remove

Influent flow, MGD x influent total phosphorus, mg/L x 8.34 lbs/gallon = lbs. influent phosphorus MGD
2.0 MGD x 8 mg/L x 8.34 lbs/gallon = 133 lbs. phosphorus to remove

Step 2: Determine the pounds of metal salt in a gallon of solution knowing the specific gravity (usually on Material Safety Data Sheet)

Specific gravity of solution x 8.34 lbs/gallon = lbs of metal salt solution to be added
1.40 x 8.34 lbs/gallon= 11.68 lbs/gallon (metal salt solution)

Step 3: Determine the pounds of actual metal in a gallon of the metal salt solution (usually on label)

Lbs of metal salt solution/gallons (*from Step 2*) x % metal in solution = lbs metal/gallon
11.68 lbs/gallon x (12.5/100) = 1.5 lbs of metal (ferric chloride) per gallon of solution

Step 4: Determine the pounds of metal needed to remove the incoming pounds of phosphorus (P)

Removal ratio x influent lbs of phosphorus = lbs/day of metal to add per lb of P to remove (*from Step 1*)
1.8 (weight ratio for ferric) x 133 lbs phosphorus = 239 lbs/day metal to add

Step 5: Determine the gallons per day of metal salt solution to add

Lbs of metal to add (*from Step 4*) ÷ lbs of metal per gallon (*from Step 3*) = gallons/day of metal salt solution
239 lbs metal ÷ 1.5 lbs of metal per gallon = 159 gallons/day of ferric chloride solution to add

From this, knowing your pump capacity, you can determine your pumping rates of chemical per hour, minute, etc.

Note: The MPCA has an Excel spreadsheet to do these calculations available upon request.

MPCA wastewater contacts

Note: E-mail addresses are firstname.lastname@state.mn.us

Contact (first, last)		Location	Telephone	Position
Ryan	Anderson	Southwest	507-476-4250	Compliance and Enforcement
Brett	Ballavance	Duluth	218-302-6619	Engineer
Nicole	Blasing	Northeast	218-302-6650	Compliance and Enforcement
Herschel	Blasing	Central	218-316-3860	Compliance and Enforcement
John	Carney	Rochester	507-206-2640	Engineer
Holly	Christensen	Northwest	218-846-8104	Compliance and Enforcement
Kay	Curtin	St. Paul	651-757-2299	Certification and Training
Amy	Douville	Metro	651-757-2661	Engineer
Steve	Duerre	St. Paul	651-757-2318	Certification and Training
Gene	Erickson	Metro	651-757-2343	Engineer
Brian	Fitzpatrick	North Central	218-316-3859	Engineer
Brad	Gillingham	Southwest	507-476-4255	Compliance and Enforcement
Dennis	Hayes	Southeast	507-206-2646	Compliance and Enforcement
Corey	Hower	Rochester	507-206-2603	Engineer
Phil	Larson	Northwest	218-846-8120	Compliance and Enforcement
Jaramie	Logelin	Northeast	218-302-6640	Compliance and Enforcement
Aaron	Luckstein	Southeast	507-206-2606	Compliance and Enforcement
Susan	Mahowald	Southeast	507-206-2604	Compliance and Enforcement
Corey	Mathisen	Metro	651-757-2554	Engineer
Eudale	Mathiason	Brainerd	651-757-2553	Engineer
Pam	Meyer	Mankato	507-344-5251	Engineer
Eric	Pederson	Metro	651-757-2645	Compliance and Enforcement
Teri	Roth	Southeast	507-344-5252	Compliance and Enforcement
David	Sahli	St. Paul	651-757-2687	Engineer
Vinod	Sathyaseelan	Detroit Lakes	218-846-8135	Engineer
Charly	Wojtysiak	Metro	651-757-2831	Compliance and Enforcement