A Wastewater Plant Operator's Guide to Better Treatment for Nitrogen and Phosphorus

Guide Purpose

The purpose of this guide is to provide mechanical plant wastewater operators with strategies to achieve better treatment for nitrogen and phosphorus.

Nutrient Background

Nitrogen and phosphorus are known as nutrients. Nutrients are known as agents of growth. In small quantities they are good; nitrogen and phosphorus are both key ingredients in fertilizer. However, in excess, nutrient pollution in the water can lead to the excessive growth of algae known as eutrophication. This eventually causes algae to outgrow the carrying capacity of the local ecosystem, choking the oxygen out of the water, and creating a dead zone that is incapable of supporting normal aquatic life, like fish.

Biological Nutrient Removal Basics

Biological nutrient removal (BNR) is the process of using microbes to remove nitrogen and/or phosphorus from the water. This is the only commonly used method for removing nitrogen from the water in mechanical wastewater treatment plants. Biological nutrient removal is a useful alternative to chemical treatment to remove phosphate from water.

Nitrogen BNR Steps

Nitrogen removal is achieved through three steps: ammonification, nitrification, and denitrification.

Ammonification is the process by which organic N (nitrogen) is converted into ammonium (NH_4). This often occurs in the collection system as the wastewater travels to the plant.

Nitrification is a process which occurs in aerobic conditions, where microorganisms convert ammonium (NH_4) to nitrite (NO_2), and then convert nitrite (NO_2) to nitrate (NO_3). Many mechanical plants currently have ammonium limits, and this nitrification process occurring in aeration tanks allows plants to meet that limit. Note that through both ammonification and nitrification the form of the nitrogen has changed, but nitrogen has not yet been removed from the system.

Denitrification occurs in anoxic conditions, where microorganisms that want oxygen but do not have a readily available source of it in the water will then take it from the nitrate (NO_3) and release nitrogen gas (N_2) out of the wastewater. This is the only common process for mechanical wastewater plants to remove nitrogen.

Phosphorus BNR Steps

Biological phosphorus removal requires two steps. The first step is to send the wastewater into a low-oxygen, anaerobic zone. An anaerobic zone is similar to an anoxic zone, except in an anaerobic zone there is no oxygen in the water or in other sources (e.g. no nitrate). In water containing no oxygen sources, polyphosphate accumulating organisms can grow. They consume volatile fatty acids (VFAs) in anaerobic conditions, and use them to become 'energized.' Keep in mind that in anaerobic conditions, they will also release phosphorus that they have previously uptaken.

Next, in aerobic conditions, after becoming 'energized,' these polyphosphate accumulating organisms (PAOs) will uptake phosphorus, become heavy, and settle out in the final clarifier, resulting in phosphorus removal from the system.

It is useful to frequently waste from the final clarifier and to frequently thicken the sludge in order to prevent the waste activated sludge (WAS) from becoming anaerobic. If WAS is stored for longer periods of time, and conditions become anaerobic, the PAOs will rerelease the phosphorus that has been uptaken. This phosphorus can then find its way back to the plant through decant from sludge thickening. High phosphate in the decant return stream can be an issue for plants using traditional chemical phosphorus removal as well. Rerelease can occur in sludge after 16-24 hours. Therefore, daily sludge wasting and sludge thickening is a useful strategy to prevent this phosphorus rerelease in the biological nutrient removal process.

BNR Tanks – Aerobic Tank

Most mechanical wastewater treatment operators are likely familiar with the aerobic or aeration tank. In aerobic conditions, aerobic microorganisms consume BOD as an energy source along with oxygen to grow. This is also where ammonium (NH_4) is converted into nitrate (NO_3) through nitrification. Aerobic microorganisms consume BOD very quickly, and tend to out-compete the anoxic and anaerobic microorganisms required for nutrient treatment. For this reason, the aerobic tank is typically placed at the end of the biological nutrient removal process.

BNR Tanks – Anoxic Tank

An anoxic tank is very similar to an aeration tank, except that it is mixed and not aerated. This creates a low dissolved oxygen condition within the tank. Additionally, this tank often receives return activated sludge (RAS) and may also receive a water recirculation stream from the aeration basin. Both of these options provide this tank with a steady source of nitrate (NO_3) which was created through nitrification in the aerobic tank. In low oxygen conditions, but in the presence of nitrate (NO_3), microorganisms that want oxygen will take it from the nitrate (NO_3), releasing nitrogen gas (N_2) to the atmosphere. Earth's atmosphere is roughly 78% nitrogen, so this process serves to return the nitrogen to its source and removes it from the water where it is a pollutant.

BNR Tanks – Anaerobic Tank

An anaerobic tank is very similar to an anoxic tank, except that it is not supplied with a source of nitrate as an oxygen source. This results in conditions with low dissolved oxygen, and no other readily available oxygen sources. This is a great candidate for being the first tank in series in a BNR process. This creates conditions where polyphosphate accumulating organisms can grow without being outcompeted by aerobic microorganisms. In this tank, polyphosphate accumulating organisms (PAOs) will consume volatile fatty acids (VFAs) and will grow and become ‘energized.’ After becoming energized in an anaerobic tank, when transferred to aerobic conditions, PAOs will uptake phosphorus. The PAOs will then become heavy, and are settled out in the final clarifier.

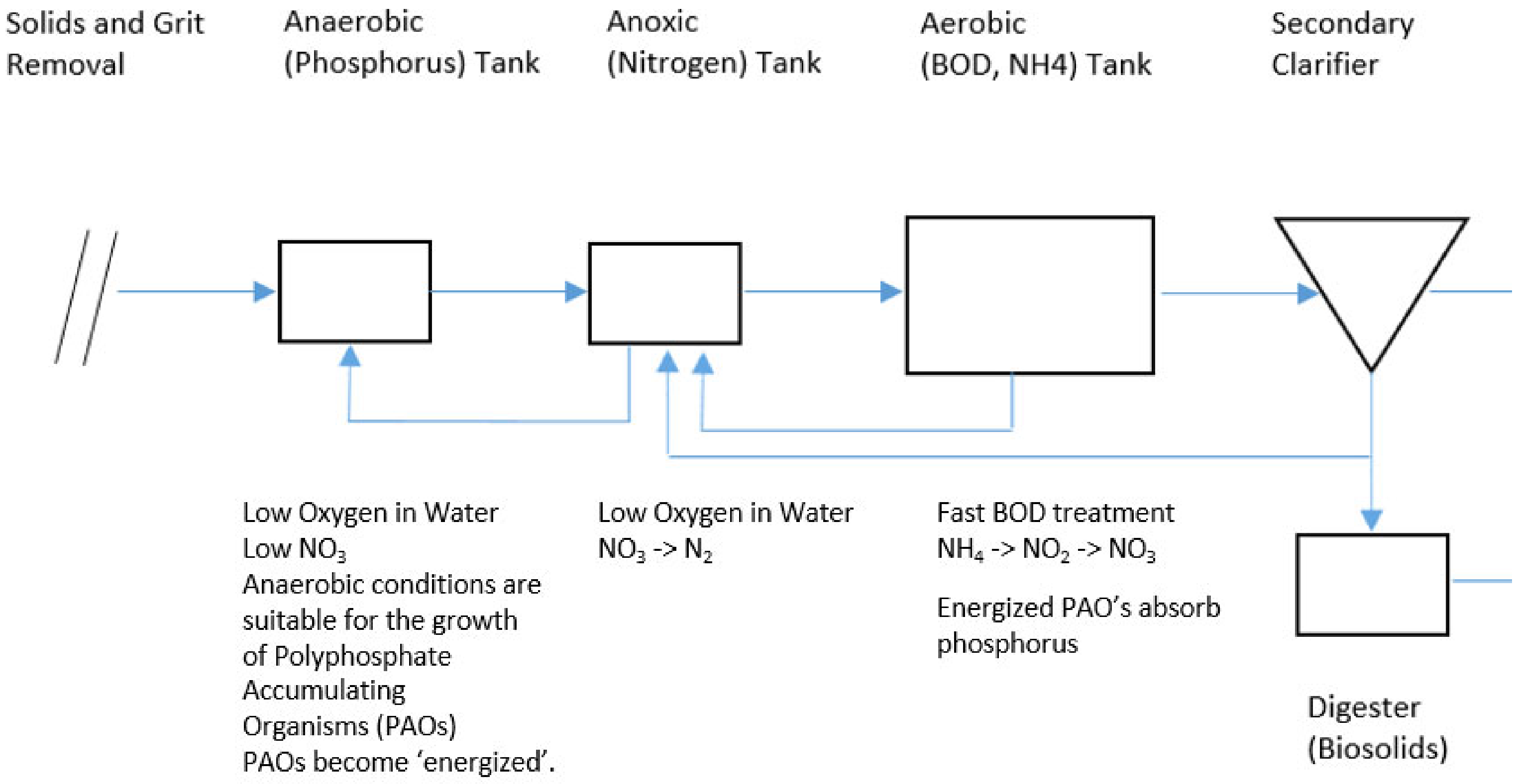
Fitting it all together – A2O Design

There are many BNR designs that have been successfully used in wastewater treatment facilities. One such example is called A2O, named because it runs with three tanks or zones in series, one anaerobic, one anoxic, and one oxic (or aerobic).

Wastewater flows into the plant, through solids separation, and then into an anaerobic tank, which creates conditions and time for the growth of polyphosphate accumulating organisms. Next, wastewater flows into the anoxic tank, which is also fed nitrate in the form of return activated sludge (RAS) and/or water pumped from the aerobic/oxic tank. Here denitrification occurs, releasing nitrogen gas from the water. Finally, water is sent into the aerobic tank, where ammonium is converted to nitrate, any remaining BOD is quickly consumed, and energized PAOs uptake phosphate.

BNR plant diagram

This diagram shows the secondary treatment process for a common A2O plant layout which can be effective in achieving biological nutrient removal.



Modifying operations to achieve BNR

Many mechanical treatment plants in Minnesota currently have a similar design. Plants are often run with three secondary aeration basins run in series. This design effectively removes BOD, effectively converts ammonium (NH_4) to nitrate (NO_3), and can also achieve phosphorus removal through chemical treatment. This design does not result in any reduction in total nitrogen, and requires continuous chemical addition to achieve phosphorus treatment.

Over the course of this project, the team developed computer simulations for ten mechanical treatment plants in Minnesota. Baseline models were created from current influent parameters, basin sizes, and flow patterns through the plants. These baseline models were then used as a starting point to investigate low cost ways to modify operations in order to achieve conditions suitable for biological nutrient removal. For most plants, the team was able to develop a strategy using the existing tanks available to achieve biological nutrient removal.

A useful early step is to create and test a plant model simulation through a program designed to model Monod kinetics (process of microbial growth and death) within the system prior to making changes at the plant. This results in creation of a theoretically working target for the real trial, and by creating an environment where various scenarios can be trialed fairly quickly in order to find theoretically strong operating points for the treatment plant.

Designs that were typically successful during the modeling stage for Minnesota wastewater treatment plants included:

> Option 1: Convert aeration tank 1 into anaerobic tank. Convert aeration tank 2 into anoxic tank. Direct RAS to anoxic tank. If needed:
>
> - recirculate water from aerobic tank to anoxic tank
> - recirculate water from anoxic tank to anaerobic tank
> - add supplemental source of COD to the influent
>
> Option 2: Convert aeration tank 1 into low oxygen tank which will serve as a dual anaerobic and anoxic tank. Direct RAS to tank 1.

> Option 3: Cycle oxidation ditch aeration on and off in order to create anaerobic, anoxic, and aerobic conditions all in one tank several times over the course of a day.

There are many other BNR design options, but those listed seemed to be simple options for modifying operations in existing Minnesota wastewater treatment plants.

Over the course of creating these models, it was also common for denitrification and PAO growth to be BOD limited. Adding a supplemental source of readily bioavailable BOD is a very common solution that can allow BNR plants to achieve much better removal of nitrogen and phosphorus.

While purchasing a carbon source can be fairly cost-prohibitive, accepting industrial waste sources of BOD can be a cost-effective option for achieving BNR. Often businesses are willing to pay a small tipping fee for accepting their waste source, and sources such as brewery waste and dairy waste are believed to be great sources of BOD for the BNR process. Keep in mind that adding an external BOD source will also increase oxygen consumption requirements of the system, so the tipping fees should ideally help to pay for the additional energy requirements associated with the additional BOD.

Reasonable BNR Targets:

Most Minnesota wastewater treatment plants have an effluent phosphorus limit of 1 mg/L. Each of the ten plant models created through this project work were able to achieve effluent phosphorus of less than 1 mg/L (although some models did require a supplemental COD source).

Half of the modeled plants in this project were able to achieve effluent nitrate in the 10-16 mg/L range, while the other half of the models showed effluent nitrate ranging from below 1 mg/L to 6 mg/L. This can be dependent on availability of influent COD, available tank sizes, and total influent nitrogen.

Chemical Treatment for Phosphorus

As an alternative to biological phosphorus removal, phosphorus can be removed fairly simply using chemical treatment. Ferric chloride ($FeCl_3$) and aluminum sulfate ($AlSO_4$) are the most commonly used chemical options for removing phosphate. The metal portion of the chemical (iron or aluminum) will adsorb to the phosphate. The metal-phosphate is denser than water, and will settle out in the final clarifier. Phosphorus treatment chemicals are often added to the wastewater stream between the aeration tank and the final clarifier.

Newer formulations are in development that use rare earth metals as an alternative to the traditional iron or aluminum formulations. The rare earth formulations are often designed to create a stronger bond with the phosphorus. Based on a presentation and associated experiments from CDM Smith,[1] ferric chloride and aluminum sulfate both required an experimental molar ratio of 5:1 for chemical to phosphate. The rare earth metal alternative that they tested required a molar ratio of 2:1. Keep in mind that molar ratio doesn't tell the full story, as rare earth metals have higher atomic mass. As of the date of this writing, both ferric chloride and aluminum sulfate tend to be fairly close in terms of cost effectiveness, while rare earth metals tend to be more expensive. However, as with any new technology, over time the new options may become more cost effective.

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[1] http://www.newea.org/wp-content/uploads/2017/02/NEWEA17_Session25_ABowen.pdf