PINE GROVE JOINT TREATMENT AUTHORITY
PINE GROVE WASTEWATER TREATMENT FACILITY
PINE GROVE TOWNSHIP, SCHUYLKILL COUNTY, PENNSYLVANIA

NPDES # PA0020915

OXIDATION / REDUCTION POTENTIAL PROBE STUDY

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pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION
WASTEWATER TECHNICAL ASSISTANCE PROGRAM

2023

Summary:

DEP and EPA staff worked with the operator and staff at Pine Grove Joint Treatment Authority's wastewater treatment facility, located in Pine Grove Township, Schuylkill County, to measure and monitor oxidation/reduction potential of activated sludge process during denitrification. The wastewater technical assistance program lent an ORP probe, mounting, and electronic controller to Pine Grove for use in one of its two sequential batch reactors (SBR) beginning at the end of November 2022 through April 2023. During this evaluation, facility staff consulted with EPA staff on a regular basis to transmit raw data from the ORP probe and from the facility's own dissolved oxygen (DO) probes, and they made adjustments to SBR timing to achieve lower total nitrogen concentration in treated effluent. Use of the ORP probe temporarily demonstrated that the facility would benefit from acquiring and installing, on a permanent basis, ORP probes in both of its SBRs for improved process control.

Recommendations:

Based on the outcome of the ORP study and additional discussions, the following recommendations are made for ongoing and future improvement:

1. Continue to maintain dissolved oxygen monitoring and control. DO trends should be readily available to the operator to see what's happening when things are good and bad. Consider having readily accessible graphics included in your SCADA programming, giving the operator ability to call up graphs covering specified periods of time. (Overall, all aspects of the operations should be accessible as graphs for assisting the operator in making process control decisions.)
2. Continue to use the laboratory spectrophotometer and test kits to monitor nutrients at the facility. Attachment E, following, is a table of TNT Plus tests used most frequently in the DEP Wastewater Technical Assistance Program for process monitoring tests. Nutrient testing should be done frequently in house, on either grab or composite process samples, at least once per week until the operators have sufficient familiarity with their facility's nutrient load to both characterize their operation and to warn them when the process is trending toward process failures. Graphing this data would prove useful internally, and providing graphs in reports to the facility owner will support the operators' work with the owner to maintain and improve process control.
3. Install ORP probes in the SBRs. During the evaluation, the facility has been operating well; however, should denitrification become inhibited, the operator would benefit greatly from having ORP data available. At times of the year when it is favorable to control the SBRs using ORP-based control, the facility will see benefits of reduced energy consumption and costs for aeration.
4. Update SCADA and primary logic controllers (PLC) for SBRs so that the operators can adjust timing (Mix Fill, Aerate Fill, Mix React, Aerate React, Settle, Decant, WAS, Idle) without having to bring in consultants each time an adjustment is warranted. Lack of control over cycle timing prevents process optimization and could lead to plant upsets if the operators are unable to adjust to changing conditions.
5. Regarding the acceptance of septage from external sources, the plant is running much better with significantly less septage input. Unfortunately, septage treatment can cause significant operations and maintenance problems at facilities of this size.
   a. When dealing with septage, assume for every pound of organic loading from incoming septage, and additional ½ pound of waste sludge must be hauled.
   b. Septage brings unknown chemical contaminants and adverse microlife that can cause settleability issues and plant upsets. It should be handled judiciously.

Background:

Pine Grove STP is a major discharger to the Swatara Creek watershed, with a design capacity for 1.5 MGD. It is located southwest of the Borough of Pine Grove, in Pine Grove Township. The facility consists of two SBR tanks each able to be operated independently of one another. A future third SBR tank is presently partitioned for use as aerobic digesters. The facility includes a modern headworks, aerobic sludge digestion, sludge dewatering, and onsite laboratory and mechanical facilities. The past operating record shows that the facility has been meeting its Chesapeake Bay nutrient reduction goals and has indeed been selling nitrogen credits in the nutrient trading program. Facility staff has been interested in process optimization and in developing documentation for advanced biological treatment.

Oxidation / Reduction Potential Probe:

Walter Higgins of the EPA Region 3 Office of Water Programs has been working with plant staff for over a year on various nuances of operations. He requested use of an ORP probe and controller at the end of November. DEP agreed to install the probe on site at the facility, and Higgins would monitor, maintain, and report its data, all while providing hands-on training to plant staff. Attachment A, following, includes photos of the installation.

DEP provided the following:
- Hach DRD-1P5 oxidation/reduction potential probe
- Hach SC200 probe controller and data logger
- Fabricated 20-ft. probe pole and swivel mount for 1-1/2" hand railings
- Selected miscellaneous mounting parts and tools

Prior to deployment, the ORP probe was recalibrated using Zobell's Solution to a standard 228.5 mV potential at 20° C.

Pine Grove's goal is to reduce effluent total nitrogen by almost half, to produce more saleable trading credits.

The following illustration depicts the oxidation / reduction potential ranges for different processes in biological nutrient reduction. The Pine Grove facility appears to treat ammonia-nitrogen to near-nondetectable concentrations. Nitrite-Nitrate concentration is typically held below 6 mg/L. The facility endeavors to generate marketable nutrient trading credits every year. If NOx concentrations were to average 3 mg/L, the operator expects he would meet his goal.

ORP Ranges (Broad) for Wastewater Processes
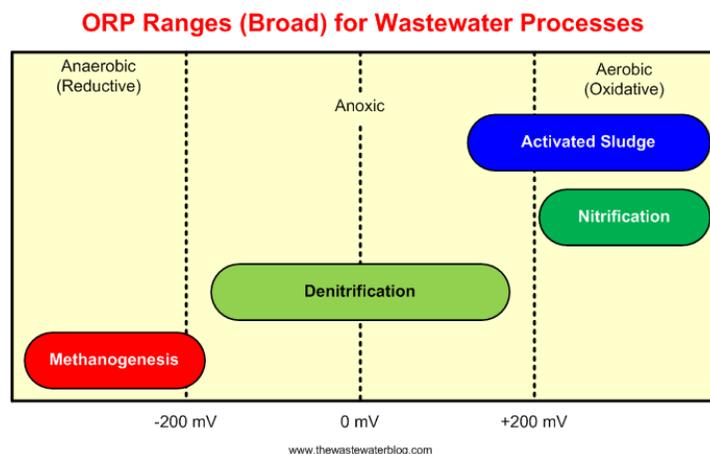
The effective range for denitrification spans from +150 mV to -150 mV on the ORP scale. Denitrification is optimized within a range of 0 mV to -50 mV, according to experience. When the ORP probe is incorporated into a facility's SCADA system, it is possible to regulate the BNR processes using ORP rather than relying solely upon process timers or dissolved oxygen content. There are periods during the year when facility operators find that ORP controlled BNR is more effective than DO or timed control, although the best operational strategies invariably incorporate all three controls as needed according to treatment conditions.

This graph of ORP and DO data from December 2022 shows the six cycles of the SBR in relation to the two measured parameters. The big picture is that when dissolved oxygen is fully depleted and anoxic bacteria begin to draw oxygen from bound sources such as dissolved nitrate in the mixed liquor, the oxidation/reduction potential dips into a zone where denitrification is optimized. This value is generally between +100 mV and -100 mV, but there exists a "sweet spot" for denitrification that, while varying from one facility to another, is

usually within the range from 0 mV to -50 mV. Having ORP available as a diagnostic and a process control tool allows the facility operator to maximize the conversion of dissolved nutrient nitrate to molecular nitrogen gas that leaves the treated water and returns to the atmosphere.
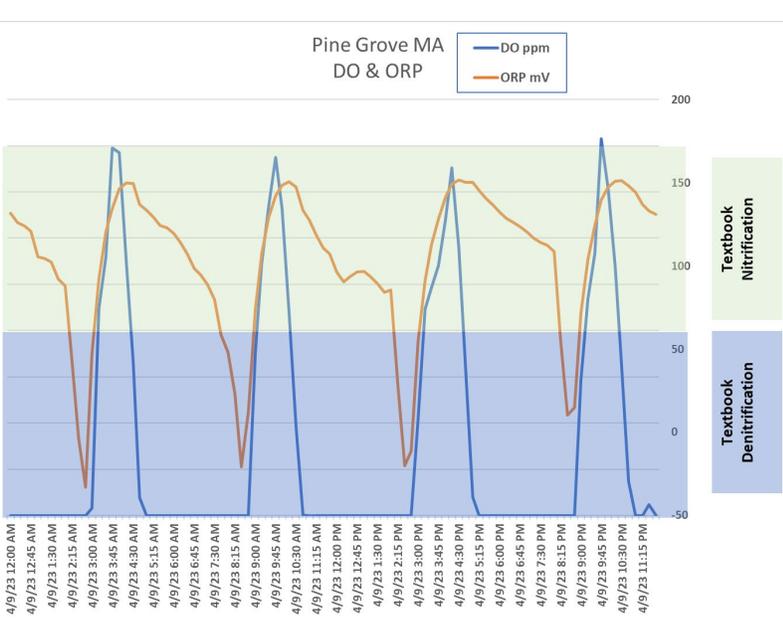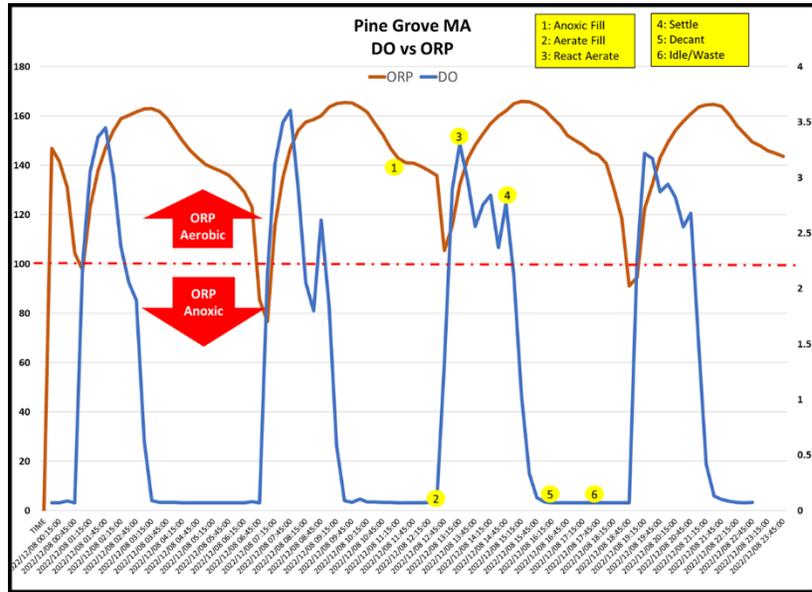
This second graph, from April 2023, illustrates ORP values against the "textbook definitions" of oxic (aerobic) and anoxic (reducing) conditions. For ammonia removal, highly oxic conditions are required. For denitrification, anoxic conditions, but never anaerobic conditions, are required. Both phases of treatment contribute to overall reduction of Total Nitrogen in the finished effluent.

Please see Attachment B, following, for additional information on nutrient removal. Attachment C discusses calculating alkalinity demand. Attachment D discuss-

es purchase and maintenance costs for ORP probes.
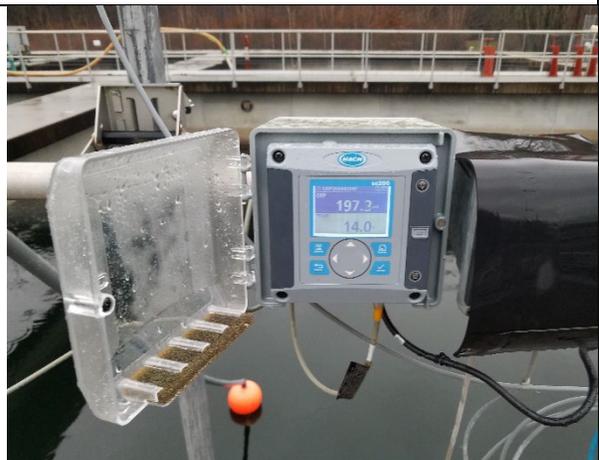
ATTACHMENT A: PROJECT PHOTOGRAPHS

View of SBR unit

SBR probe float and anchor pole

SC200 controller & data logger

ORP and Temperature readings

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ATTACHMENT B: DISCUSSION OF BIOLOGICAL NUTRIENT REMOVAL (BNR)

Why Nitrate in the Effluent is a Concern:

Dissolved nutrients in treated wastewater effluents create both environmental and health concerns. They cause over-fertilization of algae and plant growth that sets up a cycle of excessive growth followed by eutrophication and decay. The excessive growth robs the natural environment of its capacity to support local biota that are the source of food for aquatic organisms and displaces native plant species. Once eutrophication has been established, large algal die-offs result in decay that robs the aquatic environment of dissolved oxygen, causing entire aquatic populations to suffer and die. This degrades water quality for higher uses, as well, including withdrawals for drinking water filtration, swimming and recreation, angling, and other activities.

DEP has an operator training manual covering this topic, found here .

Nitrate is a pollutant of concern in surface waters filtered for human consumption and in groundwater sources for drinking water wells. EPA has set an enforceable standard called a maximum contaminant level (MCL) in potable drinking water for nitrates at 10 parts per million (ppm) (10 mg/L) and for nitrites at 1 ppm (1 mg/L). Many regulators are calling for similar limits for point-source and ground water discharges.

Human health concerns are a major factor in regulatory efforts to reduce nitrate in wastewater discharges. Exposure to nitrate also increases the risk of thyroid disease[1] and may lead to certain types of cancers of the colon and bladder[2], as well as a very specific birth defect called neural tube disorders caused early in pregnancies.[3] Nitrate acts on hemoglobin in red blood cells to form methemoglobin, reducing the oxygenation of organs and tissues.[4] Acquired methemoglobinemia in infants may occur when they consume nitrate in water used to mix infant formula or in nitrate-rich foods, medications such as benzocaine or dapsone, or through household exposure to naphthalene found in mothballs, toilet deodorants, plastics, and chemicals.[5] Nitrate may also be implicated in diabetes, miscarriages, and acute respiratory infections. The medical science on the effects of nitrates continues to develop.

Nitrification and Denitrification:

During the 1970s, treatment facilities were required to nitrify ammonia wastes to eliminate this pollutant that was killing aquatic life in receiving waters. Nitrification employs autotrophic bacteria in highly aerated conditions to convert ammonia to nitrate. The bacteria, normally found in topsoil, are found in activated sludge. During the past thirty years, microbiologists have discovered that there exist many genera of nitrifying bacteria, some of which are capable of completely nitrifying inorganic ammonia to nitrate.[6] *Nitrospira* and *nitrococcus* come to mind. Traditional explanation

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[1] Epidemiology: May 2010 - Volume 21 - Issue 3 - p 389-395 (Nitrate converts to nitrite in vitro which becomes nitrosamines, leading to a host of health issues.)

[2] Schullehner J, Hansen B, Thygesen M, Pedersen CB, Sigsgaard T. Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. Int J Cancer. 2018 Jul 1;143(1):73-79. doi: 10.1002/ijc.31306. Epub 2018 Feb 23. PMID: 29435982.

[3] Epidemiology: July 2004 - Volume 15 - Issue 4 - p S184; The Lancet, Volume 14, 100286, March 1, 2022

[4] Kross BC, Ayebo AD, Fuortes LJ. Methemoglobinemia: nitrate toxicity in rural America. Am Fam Physician. 1992 Jul;46(1):183-8. PMID: 1621630

[5] Wisconsin Dept. of Health Services website, Infant Methemoglobinemia (Blue Baby Syndrome) , (rev. 04/15/2021)

[6] van Kessel, M., Speth, D., Albertsen, M. et al. Complete nitrification by a single microorganism. Nature 528, 555–559 (2015). https://doi.org/10.1038/nature16459

of nitrification, prior to these discoveries, focused on a two-step process performed by two different genera of bacteria. These two genera of nitrifiers work in tandem: *nitrosomonas*, an ammonia-oxidizing bacteria (AOB), converts ammonium to nitrite, after which *nitrobacter*, a nitrite-oxidizing bacteria (NOB) converts nitrite to nitrate. The net reaction is shown below:

$$NH3 + O2 + H2O \quad \rightarrow \quad NO3- + 5H+ +4e \tag{1}$$

The first step reaction by *nitrosomonas* is shown here:

$$NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + 2\ H_2O + 2\ H^{+\ 7} \tag{2}$$
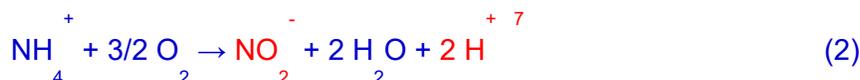
Additional oxygen and detention time are necessary to allow *nitrobacter* to oxidize the biologically active nitrite ion to chemically inert nitrate ion.[8]

$$NO_2^- + \tfrac{1}{2}\ O_2 \rightarrow NO_3^- \tag{3}$$

Nitrification requires several factors to complete the process. These include
- Sufficient detention time, 10 to 14 days: most of the cBOD must first be consumed by heterotrophic and facultative bacteria in the activated sludge.
- Dissolved oxygen residual between 1.5 mg/L and 3.5 mg/L in the bioreactor.
- 4.6 lb. of oxygen consumed per pound of ammonia converted to nitrate: this can double the amount of oxygen required, compared to only treating for cBOD.
- pH generally above 7.0 s.u., ideally between 7.3 and 8.6, but no lower than 6.5 s.u.
- 7.14 pounds of alkalinity is needed to convert every 1 lb. of ammonia.
- Alkalinity in the raw wastewater should be over 200 mg/L as $CaCO_3$ or be supplemented to assure effluent alkalinity remains between 50 mg/L and 100 mg/L after treatment.
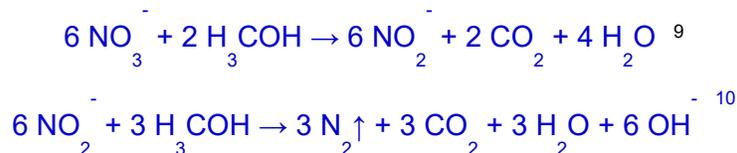- Water temperature above 5 degrees Celsius (41 deg. Fahrenheit).

Nitrosomonas and nitrobacter are very sensitive to toxicity, as well, and one or the other can easily be suppressed by the presence of many household and commercial cleaners, excessive metals, and other contaminants.

Considering these factors, it is important for wastewater operators to regularly perform process control testing to determine whether the conditions are favorable for nitrification. If nitrification breaks down, these tests may help to determine what conditions are affecting the bacteria and which, *nitrosomonas* or *nitrobacter*, are most affected. Testing for pH, alkalinity, are dissolved oxygen residual are critical to maintaining effective nitrification.

Many wastewater treatment facilities built or upgraded in recent times have been equipped for biological nutrient removal (BNR). Denitrification is a process by which facultative, heterotrophic bacteria in the activated sludge will reduce nitrate to nitrogen gas that leaves the water and returns to the atmosphere. The balanced chemical equations are shown below:

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[7] This is the first half of the reaction, converting ammonium to nitrite. The nitrite, in red, associates with the hydrogen, also in red, as nitrous acid, resulting in lower pH if alkalinity is inadequate.
[8] The chemical oxidation state of nitrate ion is such that it does not necessarily associate with hydronium to produce more acid. It more typically associates with metal ions and is inert.

$$6 \text{ NO}_3^- + 2 \text{ H}_3\text{COH} \rightarrow 6 \text{ NO}_2^- + 2 \text{ CO}_2 + 4 \text{ H}_2\text{O} \quad [9]$$

$$6 \text{ NO}_2^- + 3 \text{ H}_3\text{COH} \rightarrow 3 \text{ N}_2\uparrow + 3 \text{ CO}_2 + 3 \text{ H}_2\text{O} + 6 \text{ OH}^- \quad [10]$$

For successful denitrification, the following conditions are necessary:
- anoxic treatment conditions, where no dissolved oxygen is present. Generally, dissolved oxygen should be below 0.3 mg/L for denitrification.
- nitrate-rich environment: nitrification should be complete to the best extent possible. Nitrate dissolved in the water will provide the oxygen needed by the bacteria for metabolism.
- Presence of organic carbon as a food-source for the bacteria: usually, this comes from the raw wastewater but sometimes is required as supplemental cBOD in for form of simple chemicals like methanol, citrate, or glycerol, or as food manufacturing wastes such as molasses sugar, fruit juice waste, or whey powder.

Denitrification is a rapid reaction under the right conditions. If a treatment facility can successfully nitrify, there should be little or no problems denitrifying. In fact, in conventional and extended aeration facilities, denitrification is sometimes observed occurring in secondary clarifiers when the sludge blanket there has been retained too long: fine bubbles form in the floc causing clumps of sludge to rise to the surface. This "lava lamp" effect, called "rising sludge," can cause effluent violations when solids are carried over the clarifier weirs to the outfall. Excessive solids carryover will also inhibit downstream disinfection processes by consuming available chlorine or by occluding the penetration of ultraviolet light.

<u>Alkalinity is Critical</u>
During nitrification, the nitrifying bacteria consume inorganic carbon in the form of dissolved carbonate / bicarbonate in the water. Alkalinity provides buffering against rapid and drastic pH changes, but it also provides a source of inorganic carbon. For every pound of ammonia oxidized, 7.14 pounds of alkalinity are consumed. (Given water chemistry and cellular metabolism, this amount is often rounded up to 7.2-to-7.5 lb. alkalinity per 1 lb. ammonia oxidized.)

If the biomass is deficient of alkalinity, the AOB conversion of ammonia to nitrite will lower the pH. This is because the nitrite released from the bacteria, as a waste product, is the anionic half of nitrous acid. The metabolism of ammonia produces hydronium ion that acidifies the water. To counteract this, supplemental alkalinity is often required in many parts of Pennsylvania where, excepting the limestone-rich geology of the Great Valley and similar areas, most of the geography is naturally deficient in alkalinity. Acid-mine drainage also contributes to lowering the pH of surface and ground waters.

While the rule-of-thumb holds that a facility is in good stead if effluent alkalinity is 100 mg/L and influent alkalinity is over 200 mg/L, experience has demonstrated that facility operators should

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[9] In this equation, H_3COH represents methyl alcohol, a simple organic carbon most often used in denite filters.

[10] The carbon dioxide and hydroxyl ion combine in water to produce carbonate alkalinity. Almost half of the alkalinity consumed by nitrification is returned to the treatment process by denitrification, resulting in reductions of alkalinity needed up front as well as energy consumed in oxygenating the water.

calculate alkalinity demand in the course of their routine process monitoring and control tests. DEP has developed alkalinity calculator spreadsheet tools to aid in this, found at this website .

Using the calculator, operators enter test value for influent ammonia concentration and for influent alkalinity. Entering the estimated flow in million-gallons-per-day (MGD) calculates the ammonia and alkalinity loads present, the alkalinity required to oxidize the ammonia, and the equation produces a net result of how much additional alkalinity to add to the process.

It should be noted that conversion factors should be applied, based on the type of alkalinity chemical being deployed. These are found in a table on the following page. To use this table, select the ratio for the chemical being used and divide this into the estimated amount required to treat the ammonia to meet the ammonia effluent limit.

E.G., from the calculator and table:

51.7 lb./day as $CaCO_3$ ÷ 1.06 = 48.8 lb./day as Soda Ash

For practical purposes, the operator could round this example result up to 50 lb./day, since the Soda Ash is provided in 50 lb. sacks.

Alkalinity Required for Nitrification

Alkalinity is needed for nitrification to meet effluent limits for Ammonia-Nitrogen (NH3-N). For every pound of NH3-N that must be removed / nitrified, 7.2 lbs of alkalinity is required. A residual alkalinity of 50 mg/L is assumed for final effluent to meet pH limits but this value can be adjusted.

Check box if treatment plant has primary clarifier(s): ☐

Influent Flow (MGD)	Influent NH3-N Concentration (mg/L)	Influent Alkalinity Concentration (mg/L)	Average Monthly NH3-N Effluent Limit (mg/L)	Alkalinity Desired in Final Effluent (mg/L)
0.012	88	206	1.5	100

NH3-N that must be removed / nitrified:
(88 mg/L - 1.5 mg/L) x 0.012 MGD x 8.34 = 8.65692 lbs/day
Alkalinity needed for nitification:
8.65692 lbs/day x 7.2 = 62.329824 lbs/day
Alkalinity available for nitrification:
(206 mg/L - 100 mg/L) x 0.012 MGD x 8.34 = 10.60848 lbs/day
51.721344 lbs/day or 516.8 mg/L of alkalinity must be added for nitrification to meet NH3-N effluent limits

Example alkalinity calculator

Compounds	Alkalinity-Ratio, ppm/ppm $CaCO_3$
Soda Ash	1.06
Acetate	0.82
Hydrated Lime	0.74
Quick Lime	0.56
Bicarbonate	1.68
Caustic soda	0.8
Magnesium hydroxide	0.5

**Alkalinity ratios to use in converting alkalinity doses**

When adding any chemical to a biological treatment process, it helps if the chemical is dosed over the course of the day rather than dumped as a bulk or slug load. Therefore, it is beneficial to mix powders with water as a diluted solution and use metering pumps to deliver the chemical dose in a twenty-four-hour period. For example, if a 50 lb. sack of Calcium carbonate is dissolved into 100 gallons of water in a day tank, the metering pump should be set to deliver 4.2 gallons per hour.

PA DEP has a training manual for chemical feed systems, found here .

Inhibition of Nitrification

Many factors may lead to inhibition of nitrification. These include:

- pH out of range for the biomass, causing nitrifiers to stop reproducing and get washed out of the system.
- Low water temperature: Below 5 degrees Celsius, the biological reaction slows considerably, as see in this graph:
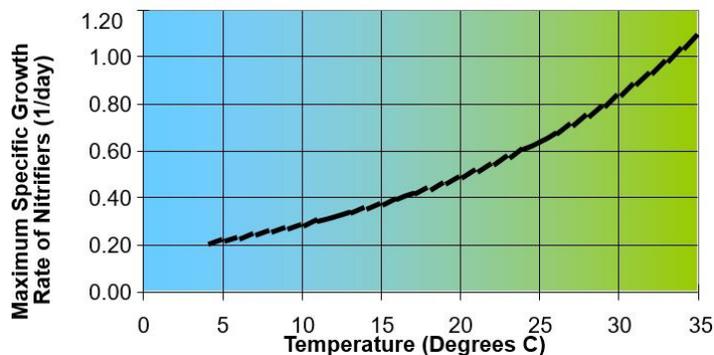
Growth of nitrifiers is dependent on temperature, and at colder temperatures, they do not replicate quickly enough to be effective
- Dissolved oxygen:
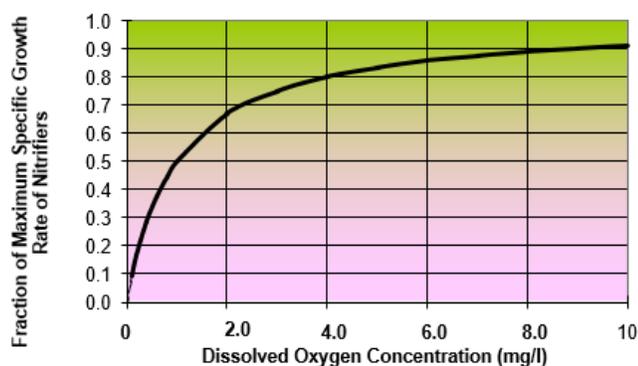
- Mean Cell Residence Time:
- Alkalinity concentration should be sufficient to maintain pH within a range from 7.0 s.u. to 8.6 s.u., and the effluent alkalinity residual should remain between 50 and 100 mg/L.
- cBOD removal:
- Toxic compounds in the wastewater will inhibit the metabolism and reproduction of nitrifying bacteria that are more sensitive to environmental changes than are the facultative heterotrophs that consume cBOD and denitrify nitrate.
- Facility design affects nitrification because of detention time, limits on hydraulic loading, quality of aeration and mixing, removal of trash and detritus, and capacity of waste sludge holding.
- Wet weather operation and inflow/infiltration affects nitrifiers because they reproduce slowly and are easily washed out of the system by hydraulic surges and overloads.

Effect of Partial Nitrification on Chlorine Disinfection

If conditions are unfavorable for complete nitrification, nitrite level will rise and exert a chlorine demand by reacting with both free chlorine and chloramines. This is called "nitrite lock." Low D.O., insufficient alkalinity, or acidic pH; high temperature or pH; and toxic or inhibitory substances will inhibit the final oxidation step from nitrite to nitrate. Nitrite lock also may occur during facility startup or during seasonal transitions, because *nitrobacter* grow more slowly than *nitrosomonas*. For example, in the seasonal temperature transition range from 10° C to 17° C, the rate of nitrite formation is slower than the rate of nitrite disappearance. 1 mg/L of nitrite will consume 5 mg/L of chlorine as Cl_2. When the nitrite concentration in the clarified effluent exceeds 1 mg/L, nitrite lock makes it seem like operators cannot add enough chlorine to their disinfection process; total chlorine residual (TRC) becomes non-detectable even at high chlorine doses, and fecal coliform counts exceed permit limits.

Since nitrite lock has many potential causes, the remedies for it are also variable. Maintaining desirable pH and alkalinity in the mixed liquor is important. Eliminating toxic or inhibitory substances in the waste stream will help, too. Sometimes these substances may be generated internally, too. For example, using small doses of liquid bleach to control filamentous growth in the biomass will likely inhibit *nitrobacter* before it affects *nitrosomonas*, resulting in higher nitrite concentrations. While water temperature cannot be easily controlled, low water temperatures generally call for longer MCRT, and this may be achieved by building up the concentration of biomass by reducing the sludge wasting rate.

For more immediate remedies to nitrite lock, if a treatment process has more than one treatment train and both are independent of one another, it may be possible to blend low-nitrite effluent with the problematic high-nitrite effluent to dilute the nitrite. Also, if the facility permit allows it, increasing the concentration of ammonia in the effluent above that of the nitrite concentration may solve the problem, because chloramines forming in the disinfection process appear to be less prone to nitrite lock than free chlorine.

Most treatment facilities test for nitrite and nitrate together. From a process control standpoint, though, it may be better to test the two separately. That way, the operators can be alert to rising nitrite concentration in time to avert problems.

Nitrogen Removal Without Major Process Changes
In modern treatment facility design, biological nutrient removal (BNR) has become common. Many process designs exist to support both nitrification and denitrification. However, it is not necessary for older treatment facilities to be radically redesigned to achieve nitrogen removal. The simplest method is called "intermittent" or "on / off" aeration, where the aeration blowers are cycled to provide either full-on aeration for oxidation of organic and ammonia waste, or turned off to provide periods of anoxic treatment where denitrification reduces nitrate to nitrogen gas in the bioreactor, preventing rising sludge from occurring in the clarifier.

Intermittent aeration requires some minor modifications to make it work successfully:
- Dissolved oxygen control: Ideally, D.O. during oxidative periods should range from 1.5 mg/L to 3.5 mg/L to achieve complete nitrification.
- Anoxic, subsurface mixing: During air "off" period, denitrification will be optimal if mechanical mixing is present in the bioreactor to maintain the bacteria, cBOD, and dissolved nitrate all in contact with one another. Without anoxic mixing, the denitrification reaction will occur mostly at the top of the sludge blanket that forms, although rising sludge (as in a clarifier) does occur, showing that denitrification will occur, albeit inefficiently, throughout the sludge blanket.
- Organic carbon: Facultative, heterotrophic bacteria that denitrify require a carbon source for cellular metabolism and reproduction. Usually, this organic carbon comes from raw wastewater continuing to enter the bioreactor while it is in the "off" period. If necessary, supplemental carbon in the form of commercially prepared additives or otherwise as simple food processing wastes, sugar, rabbit or fish food, may be substituted.

Operational Benefits of Biological Nitrogen Removal
It is said that if a facility is required to nitrify ammonia wastes as part of its NPDES permit, it should denitrify the nitrate, as well, because of the economic benefit of doing so. Nitrification is energy intensive, and there are costs associated with power consumption, maintenance costs for aeration

systems, chemical expenses associated with alkalinity addition, and use of polymer for sludge settling aids that counteract rising sludge in clarifiers.

Denitrification reduces the overall amount of power and chemicals consumed. These may be quantified as follows:

- 3.57 lb. of alkalinity as $CaCO_3$ is recovered for every 1 lb. NO_3-N reduced to nitrogen gas, N_2. Remember, 7.14 lb. of alkalinity are consumed by nitrification of ammonia, so roughly 50% of alkalinity is returned.
- 2.86 lb. O_2 is recovered for every 1 lb. NO_3-N reduced. This means the work required of motor-driven air compressors brush rotors, or surface aerators is reduced.
- Electricity conservation is observed in the use of intermittent aeration in conventional activated sludge treatment, where aeration run times may be reduced by as much as sixty percent. Activated sludge aeration need not be constant.

Case History

Intermittent aeration was tried at the Adamstown, Lancaster County, wastewater treatment facility to reduce effluent total nitrogen—mostly nitrate—so that the facility operators could save money by avoiding annual purchase of nitrogen credits to meet their Chesapeake Bay nutrient reduction goals. The facility includes two secondary bioreactors as oxidation ditches, aerated through surface mechanical aerators.

Using instrumentation to monitor dissolved oxygen, pH, and oxidation / reduction potential (ORP), and installing simple timers on the aerators' motor controls, the operators were able to reduce aeration time from 24/7/365 to 2 hours "on" and 3 hours "off" for every five-hour cycle.

Based on feedback from the instrumentation, the operator manipulated the timing regime from 24hr/day ON to 9.6 hours/day ON to optimize denitrification (TN removal). At the close of the project, effluent Total Nitrogen (TN) and energy consumption were reduced by 74% and 30%, respectively.
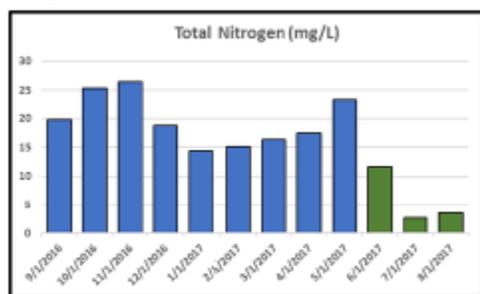

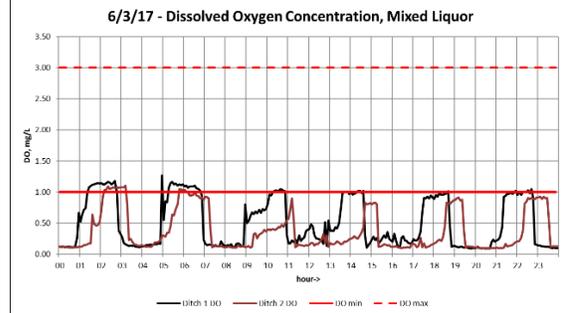Figures: Effluent Nitrogen Reduction
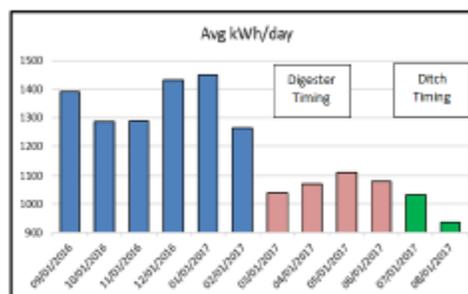
Electrical Consumption

Instrumentation and Automation

Excessive dissolved oxygen residual in bioreactors could be controlled by using variable frequency motor drives (VFD) to regulate the motors driving aeration blowers. The principle is to install continuous monitoring dissolved oxygen probes in the bioreactors and using a 4-to-20 milliamp signal from the probe controller to signal the VFD to maintain blower speed that maintains D.O. residual between 1.5 mg/L and 3.5 mg/L. The graphs below compare unregulated D.O. residual to controlled residual within aeration tanks:
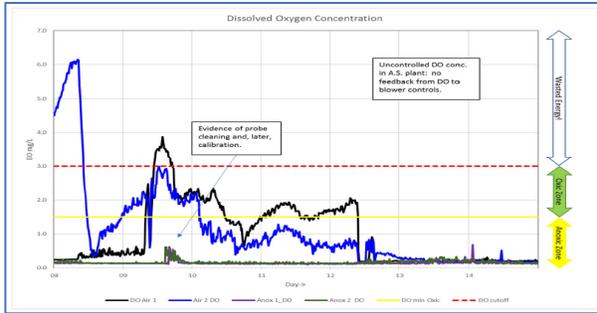
Unregulated D.O. residual in bioreactor	Controlled D.O. residual via VFD feedback loop

The technology of the dissolved oxygen probes is limited at the lower end of the scale, where any reading below 0.3 mg/L may be considered to be zero. To better understand the effective ranges for denitrification, oxidation / reduction potential (ORP) probes are used, where anoxic process is favorable between 150 mV and -150 mV. In practice, the denitrification "sweet spot" occurs between 0 mV and -50 mV, although experience may be different among differing treatment technologies. ORP probes are installed in the same bioreactor in the cases of intermittent aeration, sequencing batch reactors (SBR), oxidation ditches, Orbals, Schreiber process tanks, membrane bioreactors (MBR), and the like. Where anoxic processes occur in separate tanks, the ORP probes are placed in anoxic (denitrification) tanks or in anaerobic selectors. Process automation may use ORP probes to regulate the addition of supplemental carbon or to control the nitrate recycle rate as ways to optimize denitrification.

Because nitrifier bacteria are very sensitive to pH changes, and because the action of AOB to oxidize ammonia to nitrite produces acidification of the biomass, it is important to monitor pH in the aeration tank. Automation may use pH set points to regulate the addition of alkalinity to control pH. Nitrosomonas has an optimal pH between approximately 7.0 and 8.0 s.u., and the optimum pH range for Nitrobacter is approximately 7.5 to 8.0 s.u.

ATTACHMENT C: METHOD FOR ALKALINITY DOSING CALCULATION

Typically, alkalinity in effluent should be 50 mg/L or match that of the receiving stream; however, because of bioavailability of alkalinity at the pH range needed by nitrifying bacteria, this concentration should be higher in the Aeration Tanks, 100 mg/L up to 220 mg/L.

Alkalinity demand should be calculated. Since each 1 mg/L of ammonium in the secondary influent requires 7.14 mg/L alkalinity as $CaCO_3$[11], multiply the influent (or raw) TKN (total Kjeldahl nitrogen, which is organic nitrogen and ammonium nitrogen, combined)[12] concentration in mg/L X 7.14 mg/L alkalinity to determine a minimum amount of alkalinity needed for ammonia removal through nitrification. Then determine the influent alkalinity concentration already present and subtract this from the alkalinity demand you just calculated for your influent ammonium.

Example:

- **88 mg/L Influent Ammonia-nitrogen in Raw Wastewater**
  (Estimated that Ammonia-nitrogen is 70% of TKN in domestic wastewater)
      (88 x 100%) ÷ 70% = 126 mg/L TKN estimated
- **126 mg/L Influent TKN x 7.2 mg/L alkalinity per 1 mg/L TKN = 905.1 mg/L alkalinity required**

If the secondary influent already has 403 mg/L of alkalinity, then the net alkalinity demand is:

915.2 mg/L alkalinity needed to treat: 403 mg/L alkalinity in Influent = 502.1 mg/L alkalinity demand exists

To convert this to an actual chemical dose, you will have to multiply the net demand concentration by the Influent flow rate:

If the average flow is 0.0122 MGD, then the amount of alkalinity required would be

502.1 mg/L x 0.0122 MGD x 8.34 lb./gal = 51.1 lb./day.

To convert this to a chemical dose, you will have to determine the available alkalinity in the chemical. For example, 1 lb. Soda Ash has 1.06 lb. alkalinity[13]. This means that to provide 52 lb./day alkalinity as $CaCO_3$, you need to divide this by the ratio of chemical to alkalinity:

51.1 lb./day ÷ 1.06 = 47.3 lb./day of Soda Ash (round up to 50 lb.)

Figure adding 1 fifty-pound bag over 24 hours, not all at once. Using the 100-gallon day tank, the feed rate would be

50 lb./day ÷ 24 hours = 2 lb., 1⅓ oz. per hour (100 gal. per day = c. 4.2 gal./hr.)

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[11] To account for bioavailability of alkalinity at the desired MLSS pH of 7.2 to 7.5, substitute 8 mg/L for 7.14 mg/L. This increased the alkalinity required but is also more realistic, since 7.14 mg/L is the **minimum** required.

[12] If you can't test for TKN, substitute a test for ammonia-nitrogen and multiply the result by 1.25 to approximate the combination of organic nitrogen and ammonium nitrogen, together.

[13] See the table on the next page.

Keeping track of the alkalinity demand over time should help when determining the size and capacity of the chemical feed pump and the size of the line needed. When using this dosing method, it doesn't hurt to round up to easier quantities to work with; for example, 47.3 pounds of demand rounds up to 50 pounds.

Supplemental Alkalinity Buffering Compounds

Compounds	Alkalinity-Ratio, ppm/ppm $CaCO_3$
Soda Ash	1.06
Acetate	0.82
Hydrated Lime	0.74
Quick Lime	0.56
Bicarbonate	1.68
Caustic soda	0.80
Magnesium hydroxide	0.50

ATTACHMENT D: ORP PROBE & CONTROLLER ESTIMATED COSTS

The equipment deployed at Pine Grove for this study was comprised of Hach products. In this attachment, the estimated cost for purchasing this equipment is listed, excluding installation costs, because the work is expected to be done in-house. Modifications to the SCADA system to incorporate these probes would have to be contracted with the SCADA provider at additional programming cost.

Following is a table listing equipment needed for ORP probe installation into two SBR units:[14]

Item	Hach Cat. No.	Unit Price	Qty.	Line Cost
Hach General Purpose Digital ORP Sensor, Convertible Mount	DRD1P5	$ 1,595.00	2	$ 3,190.00
Ball Float Mounting Kit for 1" NPT Sensors	6131000	$ 1,166.00	2	$ 2,332.00
SC4500 Controller, Claros-enabled, Modbus TCP + LAN, 2 digital Sensors, 100-240 VAC, without power cord	LXV525.99AA5551	$ 3,621.00	1	$ 3,621.00
ZoBell's ORP/Redox Standard Solution, 500 mL	2316949	$ 81.39	1	$ 81.39
			Total:	$ 9,224.39

Service plans are available for these three types of probes, but care and maintenance is relatively easy to do, so maintenance plans were not explored for ORP probes. Annual maintenance would require replacement of salt bridges and equi-transferrant solution for the probes. This should be budgeted as annual maintenance costs:

Item	Hach Cat. No.	Unit Price	Qty.	Line Cost
Salt bridge PEEK, PVDF junctions	SB-P1SV	$ 124.00	2	$ 248.00
Standard Cell Solution, Concentrated pH 7.0 Buffer (Equi-Transferrant), 500 mL	25M1A1025-115	$ 113.00	1	$ 113.00
			Total:	$ 361.00

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[14] Costs are estimated based on current catalog pricing and are presented only for estimating purposes. Facility owners and operators should check and compare with equipment vendors as to the most appropriate equipment and pricing before drafting budgets. DEP makes no endorsement of any particular brand of equipment.