BNR: An Operator’s Perspective

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BNR: An Operator’s Perspective Agenda

- BNR (Biological Nutrient Removal)
  - Phosphorus and Nitrogen
- General Observations of P and N.
- Nutrient Control After Assimilation
- BNR and the 3D Floc Particle Theory
- Process Considerations
  - Loadings
  - Internal Loadings
  - Process Sensitivity
  - Environmental Conditions
- Questions
As Ohio’s regulatory framework for nutrient control carefully unfolds (or tangles into a big knot), it is becoming increasingly clear that the question for most utilities is not “if”, but “when” more stringent nutrient control will occur.

Those plants that already have nutrient limits will likely need to evaluate operation strategies to achieve even tighter nutrient limits in the future.

The process control necessary for effective nutrient compliance requires additional considerations and tighter monitoring/control on process performance and consistency.

Based on our experience at multiple facilities in Ohio and the southeast, the key areas of concern for operations are common in concept – too much air and too little carbon (cBOD5).

We hope to provide a brief overview of key aspects of process control for achieving effective and consistent nutrient removal.
Phosphorus is a conservative parameter (is discharged in the effluent or as biosolids) while total nitrogen is reduced by off-gassing to the atmosphere.

Influent phosphorus (domestic) is typically under 7 mg/L. Approximately 50% is soluble or reactive. Remaining phosphorus is particulate as polyphosphates and organic phosphates.

We consume excess phosphorus in our diet and discharge approximately 75% of what we ingest. Washing hands, showers, laundry, garbage disposals all contribute to the domestic wastewater phosphorus concentration.

Influent contribution per capita per day is approximately 2.7 grams. (approximately 1/3 is condensed). Ohio legislated a P decrease in dishwasher detergents from ~8% to 0.5% in 2010.
Using 0.45 micron filters for soluble P testing and soluble COD testing provides excellent influent tracking information as it relates to biological and/or chemical feed phosphorus compliance.

We have found ortho phosphate testing may be misleading as smaller particulate phosphate compounds will quickly break down and can provide loading to both the biological phosphorus process and the chemical trimming.

Chemical and biological treatment will only “treat” soluble or reactive phosphorus.

The particulate phosphate (polyphosphates and organic phosphates) can slow to break down and are incorporated into the biomass. Not biologically assimilated but physically incorporated.
Influent per capita contribution of N is approximately 16 g/d.

Ammonia versus organic nitrogen is 40:60 at the source. At the wastewater plant, ammonification of organic nitrogen has changed the ratio to at least 60:40.

Depending on dilution, influent concentrations of TKN (ammonia and organic nitrogen are approximately 30 mg/L).

Nitrification reduced aquatic toxicity by oxidizing ammonia to nitrate (not removing nitrogen). The nitrogen content of the nitrified effluent is only reduced by the nitrogen contained in new cell growth – assimilation.

Nitrification converts ammonia to nitrate, but allows nitrogen to remain in the effluent. Denitrification (carbon and nitrate to N gas) removes nitrogen compounds to the atmosphere.
If Biological Phosphorus removal is implemented, the phosphorus content of MLSS or biosolids can increase from 2% (lower due to debris in MLSS) to biosolids that have 16% P.

Bench scale tests have increased PAO P cell content to over 38% by weight.

Nitrogen content of sludge is not increased since nitrogen is removal is provided by off-gassing nitrogen to the atmosphere.

Biological P and Total N compliance will operate with more of the biological process in anaerobic / anoxic conditions to increase biological uptake of P and off-gassing of nitrogen.

Even with BNR, assimilation will still be the primary method of N control.
Biological assimilation of N and P:

- Assume typical biological cells are 3% phosphorus, but when accounting for the debris contained in biosolids, the P content is reduced to 2%. Assume nitrogen is approximately 12% of the sludge yield.

- Using a 1 MGD facility as an example, assume a sludge yield of 0.7 (0.7 lbs/lb cBOD$_5$ removed)

- Net cell yield is multiplied by the % cell content:
  - P is $(0.02)(0.7) = 1.4$ lbs P per 100 lbs of influent cBOD$_5$.
  - N is $(0.12)(0.7) = 8.4$ lbs N per 100 lbs of influent cBOD$_5$.

- Assume a flow of 1.0 MGD @ 160 mg/L of CBOD$_5$
Assume a flow of 1.0 MGD @ 160 mg/L of CBOD$_5$ resulted in a growth of 934 lbs of biomass /day (at the yield of 0.7).

- If 2% of the biomass is Phosphorus, 18.7 lbs of Phosphorus are removed in the biosolids through cell growth.
- If 12% of the biomass is Nitrogen, 112 lbs of Nitrogen are removed in the biosolids through cell growth.

If the influent concentration is 6 mg/L P and 30 mg/L TKN:

- 50 lbs P are received in the influent: (50 lbs – 18.7 lbs) = 31.3 lbs
- 250 lbs N are received in the influent: (250 lbs – 112 lbs) = 138 lbs

If the NPDES limits are 1 mg/L P and a total N of 8 mg/L, the effluent can only discharge 8.3 lbs/d P and 67 lbs/d N.

BNR operation must provide the following removals:

- 31.4 lbs P remaining – 8.34 lbs P by Permit = 23.1 lbs P
- 138 lbs N remaining – 67 lbs N by Permit = 71 lbs N
BNR Requirements: After Assimilation

- **Phosphorus:**
  - Biosolids P disposal has to increase from 2.0 lbs/100 lbs of biomass to 5.3 lbs/100 lbs.
  - Assume 6 mg/L in the influent, if the equivalent of 2.2 mg/L is tied up in the cell growth, 0.5 mg/L in the effluent – the equivalent of 3.3 mg/L is required to incorporated into the biosolids.
  - USEPA estimates, for example, 2.31 lbs of solids generated per pound of iron used to precipitate Phosphorus. Lowest theoretical dosage rate is 1.81 to 1 (iron to P).
    
    \[
    1 \text{ MGD} \times 3.3 \text{ mg/L} \times 1.81 \text{ dosage} \times 8.34 \text{ lbs/gal} \times 2.31 \text{ lbs solids generated} = 115 \text{ lbs/day of inert solids or a 12\% increase in sludge hauling (if chemically treated).}
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    If a 9 day MCRT, 1,035 lbs of solids carried in the biomass. If an aeration tank volume of 0.5 MG, approximately 250 mg/L of additional solids.
BNR Requirements: After Assimilation

- **Nitrogen:**
  - Total nitrogen control requires off-gassing nitrogen.
  - 2.86 mg/L of cBOD5 is required for each mg/L of nitrate destroyed.
  - A minimum of 4 mg/L per mg/L of available cBOD5 is required to drive the reaction for each mg/L of nitrate.
  - In our example, 71 lbs/d of nitrogen are required to be off-gassed through denitrification.
  - Approximately 8.5 mg/L of nitrates (71 lbs/d N) will require approximately 34 mg/L of cBOD5.
  - Approximately 21% of the cBOD5 will be required as a carbon source. On the bright side, this is an opportunity to save that much power.
  - A BNR Operator cannot afford to over-aerate and waste carbon.
Biological Phosphorus Removal

- Biological assimilation of Additional P:
  - A BNR facility would optimize biomass P uptake and increase the Phosphorus content of biomass.
  - The process would be changed to favor Phosphorus accumulating organisms (PAO) and increase the Phosphorus content of the biosolids by taking the biology through successive cycles of anaerobic release and aerobic uptake of P in the presence of a carbon source (cBOD5).
  - Biological treatment would require the addition of an anaerobic selector for mixing RAS and raw influent.
  - If enough carbon is available, the P content of the biomass could easily be tripled.
Biological assimilation of P:

- Unlike chemical precipitation, polyphosphates are formed inside the bacteria cell and held for future use by the organism.
- PAOs (Phosphorus Accumulating Organisms) are provided an influent selector process where they have first pick of the available carbon and are provided an opportunity to increase their population predominance.
- The Phosphorus is used as an energy storage medium. Any lengthy anoxic or anaerobic condition will cause a Phosphorus release as the biomass has been “trained” to provide for rapid release and intake of carbon when anaerobic.
Biological Phosphorus Removal

- Biological assimilation of P:
  - Over time, the Biosolids become very reactive in a BNR facility, and any lengthy anoxic/anaerobic cycle of the biomass could cause a phosphorus release.
  - High sludge blankets, for example, in the secondary clarifier could cause a release and noncompliance if the process is also attempting to control total N (and not over-aerate).
  - Over-aeration must be controlled or the aerobic condition of the floc as RAS would inhibit the anaerobic release of phosphorus in the influent anaerobic selector.
    - If the process is too aerobic, secondary sludge blankets could be increased to reduce aerobic poisoning of the anaerobic selector.
The 3D floc concept is used by Sedlak to describe changes in nitrification rates of the biomass. In this example, the BNR process must cycle between aerobic nitrification and phosphorus uptake, then when returned as RAS, deep cycle into an anaerobic state for phosphorus release and anaerobic cBOD5 uptake.

If the process is too aerobic and the floc is fully aerobic, there is a long cycle time requirement before the floc can return to an anaerobic condition. Time and carbon are squandered if over-aerated.

Total N compliance requires the MLSS floc to fluctuate between aerobic and anoxic/anaerobic conditions with remaining
The 3-D Floc concept allows for changes in ORP demand due to load or floc condition. Sedlak was using the concept for changes in nitrification rates with the same dissolved oxygen concentration while varying the load.
The ORP MV readings suggest values that are the sum of the oxidation and reduction reactions.

The operator of a BNR facility cannot afford to over-aerate. Not necessarily watching for high dissolved oxygen conditions, but too aerobic of a condition (low f/m with sustained aerobic conditions).

The activated sludge process with only nitrifying requirements has a large bandwidth of control. Maintaining optimum biological phosphorus release and uptake requires much tighter aeration control. Maintaining BioP and Total N BNR operations requires the tightest controls for aeration and recycle flows (RAS, IR, Solids Handling)....
On line analysis – loading and ortho P. Ammonia at 0.1 mg/L
The BNR Balance in an Large Reactor

• Biological assimilation of P:
  • Although effluent ammonia remains consistently below 0.1 mg/L, the large oxidation ditch is difficult to optimize for P uptake and retention while not over-shooting and exceeding the total N limit.
  • Nitrate averages 4.6 mg/L with peaks of 7.0 mg/L.
  • The loading sag creates enough of anoxic stress on the biological floc to cause intermittent releases of P. This is coupled with the loading increase of P.
  • If total N limits were not a concern, the system would be operated more aerobically during dirunal cycles to reduce the load sag. ORP is limited in response due to the large single reactor.
Process Considerations with BNR

**Loadings:**

- Low load periods have a significant impact on dissolved oxygen “poisoning of anaerobic PAO selectors.
- Some POTWs operate with nutrient deficient loadings from paper mills, dairies, cheese houses, chocolate and other high carbon/low nitrogen influent. Do not mistake assimilation (cell growth nutrient uptake) with BNR operation for additional P uptake or improved denitrification reducing nitrate discharge. Lower nutrients are due to the increase in assimilation, not BNR.
- If available carbon is reduced, the corresponding release and subsequent uptake of P is reduced. If environmental conditions are optimum, carbon drives both BNR processes.
Loadings:

- Industrial loadings that include high amounts of particulate phosphates (food service is most notable), will show high total P influent loading, but may not have a corresponding impact on effluent quality - ortho P in the effluent.

- If there is industry (any food service such as prepared foods, dressings, dairy products, cheese or ....) on your collection system...the sanitation shift (3rd) shift will likely use phosphoric based cleaners. There will be a significant increase in influent phosphorus loading with low diurnal carbon. This will stress the biological phosphorus process and cause a bleed through of phosphorus in the process that you may not see until afternoon in the clarifiers.
Loadings:

Soluble P can be broken down quickly if loading at the headworks is not initially tested as ortho p.

Typically domestic P loading is consistent and arrives with carbon loading.

Ortho P is the biological and chemical loading requiring treatment. Remaining particulate P can be physically incorporated into the biomass without requiring the carbon cycle and/or chemical trimming.

As biological phosphorus is successfully implemented, effluent suspended solids have more of an impact to phosphorus compliance. Plants with biomass solids in double digit P concentrations are limited in effluent suspended solids by phosphorus permit requirements.
Internal Loadings:

- As biological phosphorus removal is optimized, the biology is “trained” by the BNR process to release phosphorus as a method of carbon uptake under anaerobic conditions.
- Once aerobic, the biology’s uptake and retention of phosphorus is tenuous.
- If biology becomes anaerobic in a sludge blanket, or allowed to settle while being pumped to dewatering or held as MLSS in a tank that is being drained back to the head of the plant (after taken out of service); there will be a phosphorus release that must be treated by the on-line process. This is ortho P that requires biological uptake or chemical precipitation.
**Process Considerations with BNR**

- **Internal Loadings:**
  - The less chemical precipitation, the more sensitive and greater the biological P release from dewatering, tank draining, or sludge thickening.
  - Chemical treatment of phosphorus retains a stable particulate form while the biological storage of polyphosphates will quickly convert to soluble P and bleed through the system.
  - Phosphorus release precedes ammonia release when going to anaerobic conditions.
  - Total N compliance is problematic as oxidizing the ammonia nitrogen in the recycle may be possible, but excess carbon to drive the denitrification process is limiting.
Process Considerations with BNR

- **Process Sensitivity:**
  - Carbonaceous removal is the most robust biological process. Nitrifiers are more sensitive to environmental conditions while PAOs are first to show process stress (most sensitive).
  - Loss of phosphorus uptake will precede loss of nitrification (if inhibitory influent is present).
  - Just as separate cultures are optimized for nitrification, phosphorus accumulating organisms must also be selected and the population optimized for increased accumulation of P in the biomass.
  - BNR introduces carbon for the first time in limiting both P and nitrate removal. Too much air is not just a waste of energy, it can be a noncompliance issue.
Environmental Conditions:

- Low temperature operation is more difficult for BNR operation. Dissolved oxygen is more soluble and higher concentrations retained in the liquid while biological respiration is slowed.

- Diurnal low load periods in cold weather are the most difficult to recover BNR performance. If necessary shutdown portions of aeration during the low load periods. Unlike before, noncompliance is more probable during low load periods rather than peak loading periods. Just mixing can cause an increase in ORP, decrease temperature and continue to waste carbon in cold weather.

- RAS Flow Rates: Optimum RAS control with a slight blanket will help to de-oxygenate and pre-condition RAS for the anaerobic selector process.
**Environmental Conditions:**

- **Internal Recycle Flows:** It is best to operate at minimum internal recycle flows to better optimize nitrification and denitrification within the process zone. High recycle rates coupled with excessive aeration will “wash out” anoxic and anaerobic zones.

- High recycle rates are a self-fulfilling prophecy. Higher recycle rates wash out upstream anoxic zones and increase the overall aerobic condition – requiring even higher recycle rates to trim the nitrates.

- **Storm Modes of Operation:** High dilute flows will wash out anaerobic and anoxic zones. Anaerobic zones should be bypassed and only receive RAS flow during storm or peak flow conditions.
**Environmental Conditions:**

- Overshooting with dissolved oxygen is more difficult to recover than undershooting. Effluent ammonia is used as the aerobic “condition” indicator. There should be trace amounts of ammonia to give perspective to oxygenation.

- If you overshoot the aerobic portion of your process, increasing nitrate recycle will only serve to wash out your anoxic zones and that control technique will not provide compliance.
  - More internal recycle carries more residual oxygen, more nitrate and reduces the detention time in the anoxic zone.
  - The point of control is the aerobic zone. Careful control of the aerobic zone allows for limited recycle and the process is more resilient to changes in loading.
Environmental Conditions:

- ORP control is more pro-active than dissolved oxygen. ORP control can trim oxygen delivery without requiring enough aeration to measure dissolved oxygen directly by a sensor.
- Independent zone operation and sensor placement are critical to control.
- Real Time Monitoring of nutrient parameters (NH3, P, NO2, NO3) is accurate and reliable.
- Many trends and process insights would go unnoticed without real time monitoring.
- Real time monitors such as ORP, suspended solids, dissolved oxygen, and pH will help to complete the BNR process control picture.
I don’t even want to know what is in the sample containers....

QUESTIONS????