Starting Up an Underloaded Biological Nutrient Removal Process

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In wastewater treatment facilities, some unit processes can be designed to be extremely flexible for varying flow rates and loads of wastewater. Examples of unit processes that will sometimes operate better at lower than designed loading rates include mechanical bar screens, tertiary filters, pump stations, and clarifiers. Processes that are difficult to operate in an underloaded state are biological treatment processes, including aeration basins; biological nutrient removal (BNR) systems; oxidation ditches; anoxic basins; and anaerobic basins for biological phosphorous removal. This difficulty is compounded when starting up new or altered facilities, especially when the Facility has permitted nutrient discharge limits. This article presents an example of an extremely underloaded startup (less than 50 percent of capacity and less than 30 percent total nutrient capacity) and some key metrics and potential pitfalls to consider when starting up or operating such a facility.

Facility Expansion

Pre-Expansion Facility

Polk County's Northeast Regional Wastewater Treatment Facility (Facility) was an existing wastewater treatment facility rated for an average annual treatment capacity of 3 mil gal per day (mgd), with a maximum month influent five-day carbonaceous biochemical oxygen demand ($CBOD_5$) of 246 mg/l and Total Kjeldahl Nitrogen (TKN) concentration of 40 mg/l. The Facility is located near the intersection of Interstate 4 and U.S. 27, in close proximity to theme parks and near the border to Osceola County, Lake County, and Orange County. The Facility typically discharges a portion of its effluent to rapid infiltration basins (RIBs) for aquifer recharge. The RIBs have a receiving permitted limit of 12 mg/l of nitrogen as nitrate to prevent a buildup in the soil.

The existing biological treatment unit process consisted of two Carrousel-type oxidation ditches, each rated for 1.5 mgd. Each oxidation ditch has a volume of 0.75 mil gal (MG) for a hydraulic retention time (HRT) of 12 hours. With a designed operating mixed liquor suspended solids (MLSS) concentration of 3,500 mg/l, a solids retention time (SRT) of 8.8 days is achieved. The ditches did not have anoxic zones and were capacity-limited when approaching their aeration limits due to their limited ability to remove nitrates through biological denitrification.

The upstream and downstream unit processes will not be discussed significantly due to their ability to handle fluctuating flow more easily. Downstream processes are affected by the ability of the biological processes to perform correctly. When anoxic conditions are not achieved prior to entering the clarifiers, it is common for denitrification to occur in the clarifiers, leading to a condition known as sludge "pop-ups."

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Figure 1. Schematic Layout of Biological Nutrient Removal: One Operational Mode

Expanded Facility Design

When the Facility expansion design began, the area was experiencing significant growth, with new development being permitted and constructed within the service area. When the original design began in 2006, it was expected that the Facility would be receiving more than 3 mgd by the start of 2010. To accommodate the expected growth, the Facility was originally thought to require 9 to 12 mgd of treatment capacity. Although growth slowed, it was expected that the Facility still had an immediate need of 6 mgd of treatment capacity, with the capability to upgrade to 9 mgd in the future. To compound the hydraulic capacity requirements, influent sampling during the preliminary design indicated the maximum month $CBOD_5$ strength of the wastewater had increased from 246 mg/l to approximately 600 mg/l and the influent TKN had increased from 40 mg/l to approximately 65 mg/l. The increase in loading meant that the future Facility would need to provide significantly more oxygen per unit volume of wastewater on an actual oxygen requirement (AOR) basis than the original design contemplated. The oxygen demand for the expanded Facility was estimated to be 52,736 lb/day (AOR) based on the design flow rate of 6 mgd versus 12,384 lb/day for the original 3-mgd design.

To augment the existing oxidation ditches, a BNR process was proposed with extensive flexibility. The process has a minimum treatment volume of 2 MG, with a "floating" equalization volume of 1.5 MG, for a total volume of 3.5 MG. The design MLSS for the Facility was increased to 4,000 mg/l to decrease the volume required so that an SRT similar to the original design could be maintained. This also maintained similar hydraulic retention tine (HRT) metrics with the existing plant.

The BNR is split into four equal-size tanks, with each tank having three aeration zones in the center and two nonaerated zones, one at each end. The air can be distributed through any, all, or none of 12 total aeration zones, each with a capacity of approximately 1,400 standard cubic feet per minute (scfm) per zone using fine bubble aeration. The eight zones that do not have aeration are located at each end of each tank. At the western end of each tank, recycling propeller pumps allow for the return of up to 6 mgd per propeller pump to the eastern end of the tank.

One of the intended operational modes of the biological treatment (as depicted in Figure 1) has the raw wastewater and return activated sludge (RAS) enter the BNR at the east end of Tank 1 going west. The mixed liquor path changes direction and travels north to Tank 2, then heads east. At the eastern end of Tank 2, the mixed liquor enters Tank 3, changes direction, and heads West in Tank 3. Finally, the mixed liquor enters Tank 4, heads east, and exits the process at the east end. The flow can either go to the existing oxidation ditches for polishing treatment, with the oxidation ditches operating either in parallel or in a series, or bypass them and go to the clarifiers for clarification. With key recycle pumps in the BNR, the nitrates created by nitrifying bacteria can be returned to anoxic zones for nutrient removal.

In the mode of operation discussed, the biological treatment system was envisioned to be operated with the influent BNR tank, Tank 1, having an anoxic zone at the front, followed by an aerobic zone. The recycle pump in Tank 1 was intended to be on to allow for nitrogen recycle and nutrient removal. The western end of Tank 2 was intended to generally be an aerobic zone, followed by anoxic at the east end as the mixed liquor enters Tank 3. The eastern end of Tank 3 was intended to be anoxic, followed by aerobic at the western end, with the recycle pump in Tank 3 being on for nitrogen recycle. Finally, the western end of Tank 4 was intended to be aerobic, followed by the eastern end being anoxic. Following the anoxic area in Tank 4, the mixed liquor flow would either go to clarification or enter an aerobic zone in Oxidation Ditch #1, followed by an anoxic zone. The mixed liquor in Oxidation Ditch #1 would then travel to Oxidation Ditch #2 for a final aerobic zone, followed by an anoxic zone.

Denitrification is accomplished by recycling nitrified mixed liquor from Zone 5 in Tanks 1 and 3 to Zone 1 in Tanks 1 and 3, respectively, which operate in an anoxic mode. Tank 4 has an anoxic zone present near the outlet to allow for denitrification that had not previously occurred, increasing the ability of the clarification if the oxidation ditches are bypassed. The amount of operational flexibility built into the BNR process requires a determination of how large the anoxic zones and aerobic zones will be, the selected oxidation reduction potential (ORP) for process control, and a selection of the amount of nitrogen recycle flow desired. The process calculations will be discussed.

Facility Influent After Expansion

The housing market had a sudden downturn during the design, and the slump continued throughout the construction of the Facility. The result was that the influent flow was only about 2.5 mgd when the expanded Facility was ready to be placed in operation. With all package plants in the same area diverted to the Fa-

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cility, maximum month influent flows of approximately 3 mgd were recorded. In addition, the strength of the influent wastewater was more in line with what was seen prior to the peaking events, or in the range of 300 mg/l $CBOD_5$. The influent nitrogen was still high at about 50-60 mg/l TKN, but not near the levels routinely seen during the design period.

With all four BNR tanks and both oxidation ditches in operation, the HRT was determined to be approximately 28 hours and the SRT, excluding equalization, would be 22.3 days based on a MLSS of 4,000 mg/l as designed. The new RAS pumping system was capable of being tuned to 3 mgd at a concentration of approximately 8,000 mg/l, and was not an operational problem for the process.

While this extensive aeration capability and long SRT leads to relatively easy treatment of $CBOD_5$ and quick nitrification of ammonia, it can be tricky to operate the Facility under these conditions and still meet effluent nutrient limits. Upon initial startup of the facility, some of the parameters were adjusted to allow for the Facility to operate better, such as lowering the MLSS to about 2,000 mg/l, resulting in an SRT of approximately 11 days. Operations staff was still recording a steady increase in effluent nitrate levels; in some instances, nitrate levels exceeded influent nitrogen levels. It was also noted that the effluent quality of wastewater leaving the BNR was sometimes better than the effluent quality of the wastewater leaving the oxidation ditches. It is speculated that nitrogen fixation and ammonification was occurring, where nitrogen in the air was being converted to ammonia (Leschine, et al., 1988) then nitrified to nitrates due to the presence of anaerobic conditions, followed by very aerobic conditions. Although evidence indicated nitrogen fixation, more data would be necessary to prove it was occurring. Ammonification of TKN and nitrification was evident due to the increase in nitrates through the process.

Operational Calculations

Process Recalculations

Operations staff was experiencing difficulties meeting effluent nitrate requirements. Process calculations were revisited utilizing influent flow rates of 2.5-3.5 mgd with biochemical oxygen demand (BOD) and TKN concentrations of 275-300 mg/l and 50-60 mg/l, respectively. The sizing of ideal treatment unit processes was considered based on both current and projected flow rates and loadings. It was expected that the nutrient loading would be much higher than what was actually measured, and influent flow would be close to 3.5-4.5 mgd with the diversion of flow from existing package treatment plants in the service area.

Recalculation of the ideal unit process parameters was performed in order to allow the processes to work at their peak. While the BNR has the capability of aeration and anoxic, among other treatment capabilities, if the zones are not sized effectively, the treatment processes can get out of control, leading to large swings in both oxygen demand and effluent water quality from the biological unit process.

Food to Mass Ratio and Solids Retention Time

The first items to consider are the food to mass (F/M) ratio and the SRT. The BNR was installed with fine bubble aeration and should, therefore, not be left without water in the basin. To lower the SRT to approximately eight days, as intended, both oxidation ditches would have to be removed from the treatment process and the MLSS would have to be lowered. It was calculated that if the MLSS was set to approximately 2,500 mg/l, the SRT would be 7.9 days, excluding equalization volume. This would also achieve an F/M ratio of approximately 0.18-0.2, which is ideal for the treatment process. If the process were to be started up with all bays functioning and the MLSS at 4,000 mg/l, the F/M ratio would be only 0.07, or far below the levels needed to sustain the process. The following are examples of the equations used to size the SRT and F/M ratios (Metcalf & Eddy, et al., 2003):

$$SRT = \frac{\sum Solids}{DailySolids} = \frac{MLSS * Volume}{0.84 * BOD} = \frac{41{,}700lb}{5{,}246lb} = 7.9days$$

$$F/M = \frac{BOD/day}{0.75 * MLSS * Volume} = \frac{5{,}734to6{,}255lb}{31{,}275lb} = 0.18to0.2$$

It is more common to calculate the SRT with the rate of wasted sludge, but the calculations can be compared to each other to verify actual yield of MLSS from BOD and to confirm the calculations based on wasting rate are correct.

Anoxic Zone Requirements

The primary anoxic zone was the next item to be considered. The specific denitrification rate (SDNR) was calculated based on the typical minimum temperature of the wastewater. The size of the anoxic zone required is based on the nitrogen to be denitrified, the SDNR, and the volatile portion of the MLSS, or mixed liquor volatile suspended solids (MLVSS). Because of the need for $CBOD_5$ in the denitrification process, it is critical that the anoxic zone be located at the front of the biological process to allow it to be most effective. Based on the revised influent characteristics, and a flow rate of 3 mgd, the minimum size of the anoxic zone was determined to be 0.477 MG and the ideal size was determined to be approximately 0.729 MG, which allows for conversion of some of the organic nitrogen to ammonia/ammonium. The following are examples of the equations used to size the anoxic zone (Metcalf & Eddy, et al., 2003).

$$SDNR = 6.40E10 * e^{-15880/RT} = 6.40E10 * e^{-15880/1.987*297} = 0.132lb/lb*d$$

$$V = \frac{N_{denit}}{SDNR * MLVSS} * 3MG/day = \frac{(50-1.75-6)mg/l}{0.132/d * 1{,}875mg/l} 2.5MG/d = 0.477MG$$

$$V = \frac{N_{denit}}{SDNR * MLVSS} * 3MG/day = \frac{60mg/l}{0.132/d * 1{,}875mg/l} 3MG/d = 0.729MG$$

The volume equation for the anoxic sizing allows removal of the influent TKN as ammonia, and while increasing that value, allows conversion of organic nitrogen as BOD to ammonia/ammonium, which can occur if slightly anaerobic conditions exist at the end of the anoxic zone. The first volume calculation of the size of the anoxic volume has no safety factor and is typically the minimum volume to be effective only for denitrification. The nitrogen removal equation is somewhat conservative; the low wastewater temperature is actually about 26°C and not all TKN can be removed through denitrification. These values are higher than the "rule of thumb" volumes for hydraulic retention times of 2-4 hours due to higher than typical influent TKN values.

Recycle Rate

The nitrogen recycle rate is typically determined by the target effluent nitrogen. There is typically no penalty for over-recycling to the anoxic zone, except that $CBOD_5$ will be utilized early in the treatment process. Using too much $CBOD_5$ early for aeration can lead to the need to add a carbon source later in the process, adding to the expense of the operation. With a properly-sized anoxic zone, and a recycle rate of five times influent (3 mgd influent in this case), the nitrate effluent was calculated to be 6 mg/l. Therefore, the recycle rate was set at this rate to allow for maximum reduction of nitrate in the effluent. The following equation is used to calculate the required recycle rate for removal of nitrates (Metcalf & Eddy, et al., 2003).

Oxygen Requirements

$$R_r = \frac{NH_{4i} - NH_{4e}}{NO_{3e}} - 1 = \frac{50mg/l - 1mg/l}{6mg/l} - 1 = 7.17$$

$$R = \frac{\sum IR(MLSS) + RAS}{Q} = \frac{3 * 6MGD + 3MGD}{3MGD} = 7$$

The AOR, without a safety factor, was calculated to check if the process was providing theoretical sufficient oxygen for the influent

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BOD and TKN. The following is a calculation of the AOR in lbs for the existing system:

$$AOR = Q*(kS + 4.57*(inTKN - efTKN) - 2.86*(inTKN - effTN))*8.34 =$$
$$3MGD(1.0*300mg/l + 4.57*(60-2)mg/l - 2.86(60-8)mg/l)*8.34 = 10{,}417 lb/day$$

Note that a credit was given for anoxic use of nitrates, which is typically on the order of 2.86 lbs of oxygen per lb of nitrate reduced (Metcalf & Eddy, et al., 2003). There was not a safety factor of 1.1 for the kS due to the use of real experimental efficiency in the aeration calculations in later calculations (Ott submittal, 2009). Finally, the aeration volume was calculated to see if the process had sufficient volume to achieve full BOD oxidation and nitrification. The following calculations show the minimum aerobic volume required to achieve full BOD oxidation and nitrification (Metcalf & Eddy, et al., 2003):

$$u_m' = u_m e^{0.098(T-15)} * \frac{DO}{K_{O2} + DO} * [1 - 0.833(7.2 - pH)] =$$
$$u_m' = 1.0 * e^{0.098(24-15)} * \frac{2mg/l}{1.3 + 2mg/l} * [1 - 0.833(7.2 - 7.8)] = 2.20/day$$
$$k' = u_m'/Y = 2.20/0.2 = 10.99/day$$
$$\theta_c^M = 1/(Yk' - k_d) = 1/(0.2*10.99 - 0.05) = 0.466 day$$
$$U = \left(\frac{1}{\theta_c} + k_d\right) * \frac{1}{Y} = \left(\frac{1}{0.466} + 0.05\right) * \frac{1}{0.2} = 10.98 lbBODremoved/lbMLVSS$$
$$\theta = \frac{BOD}{UX} = \frac{300mg/l}{10.98*1875mg/l} = 0.015 days = 0.35 hours$$
$$\theta = \frac{N}{UX} = \frac{(60-1)mg/l}{10.98*1875mg/l*.08} = 0.036 days = 0.86 hours$$
$$V_a = \theta * Q = 0.036 day * 3MGD = 0.107MG = 107{,}477 gallons$$

Note that these calculations exclude typical design safety factors of 2.5 and are truly the minimum. Even with the safety factors, it can be seen that the rate-limiting step for oxidation is nitrification. Because of the high temperature of the wastewater, the volume required in practice is extremely limited and is easily met, which is why dissolved oxygen (DO) had to be decreased to match the true demand. With the DO decreased to 0.19, the total time required for full nitrification is approximately 0.167 days, or a volume of 0.5 MG for the first aerobic zone. This approximately matches the values seen in the field.

Process Calculation Comparison

Table 1 is a comparison of the actual wastewater and process demands versus the design values of the plant. The 6-mgd design example provided indicates what the process values would be if the full volume of the BNR and oxidation ditches were utilized, if the design MLSS were held, and the maximum aeration rate were utilized. It is not intended to indicate an actual operational condition.

Operational Modifications

Due to the manner in which the recycle pumps were installed, it is critical that nitrification is achieved in the first tank in which the wastewater enters, and that the nitrified wastewater is recycled back to the front of the tank into the anoxic zone. This will allow for a large amount of nitrogen conversion early and for much of the nitrogen to leave the process as off-gas. Based on the process installed, at least two of the zones in the influent tank (Tank 1) had to be anoxic, and a third zone ideally would be slightly anoxic. The fourth zone then must be aerobic, with an ORP level high enough to nitrify (not high enough to satisfy all of the $CBOD_5$ demand) and low enough not to bleed the aerobic environment into the fifth zone where the nitrogen recycle pumps sit recycling the nitrates. With operational trial, this level was determined to be in the range of +25 to +50 ORP in the fourth aeration zone by splitting air between the third zone and fourth zone, having the probe in the fourth zone. Note that the exact set point requires some trial and error and will vary greatly based on the temperature of the wastewater and actual organisms present.

The second tank (Tank 2) was utilized to stabilize the wastewater, allowing for organic nitrogen conversion and additional denitrification. The air was spread uniformly with a target ORP in the range of 0 mV +/- to keep the wastewater active and in the anoxic range, but not overaerate it. This will allow for conversion of organic nitrogen to ammonia which can take time, except the nitrogen that is assimilated as solids.

The process in Tank 1 was emulated in Tank 3 with slightly lower ORP set points. Tank 3 would then nearly fulfill the $CBOD_5$ demand for the wastewater. The recycle rates are set at similar flow rates to allow for optimal nitrate removal, reducing the minimum nitrogen effluent to close to 6 mg/l. By satisfying the oxygen demand in Tank 3, Tank 4 is able to operate in a similar manner to Tank 2, stabilizing the wastewater and allowing for denitrification before the MLSS goes to the clarification unit process for solids separation. The ORP set point, at the effluent of Tank 4, controls the aeration in Tank 4. To allow for faster and tighter control for the air to Tank 4, it is ideal to have a feed-forward loop by mixing the MLSS with the nitrogen recycle pump in Tank 4, as nearly all treatment has already occurred and the penalty will not be great, even if a "slug" is encountered.

With the volumes and aeration rates for the processes calculated, it was determined that, even with a significant safety factor, the oxidation ditches were not needed in the immediate future to meet effluent quality if all four tanks of the BNR are in operation. Not only were they not needed, the effluent water quality would be better without them and the cost of Facility operation would decrease. The reason for the effluent quality being better without the oxidation ditches is due to the inability to "turn down" aeration below 60 percent of speed, or approximately 36 percent of aeration capability.

Table 1. Calculated Process Values For Operation

		3 mgd Actual Flow Recalculated		6 mgd Design Operating at 3 mgd	
Process Value	**Units**	**Calculated (Except Aeration)**	**Actual (Except Aeration)**	**Designed**	**Actual (If Max Aeration Used)**
TKN	mg/l	60	60	65	35
CBOD5	mg/l	300	300	600	300
SRT	Days	7.9	7.9	8.0	22.3
HRT	Hours	16	16	14	28
MLSS	mg/l	2,500	2,500	4,000	4,000
MLVSS	mg/l	1,875	1,875	3,000	3,000
RAS	MGD	3	3	3	3
F/M Ratio	NA	0.20	0.20	0.19	0.07
SDNR	NA	0.132	0.132	0.132	0.132
Anoxic Volume (min, first)	MG	0.477-0.729	0.800	1	0.15
Oxygen Requirement (SOR/AOR)	lb/d	SOR 25,040	AOR 10,417	97,000	40,352
Aeration Requirements	scfm	2,555	1,200-3,000	6,700 – 8,400	6,700 – 8,400
Total Nitrogen Recycle	xQ	7	7	3	3

To achieve better results and additional recycle return, it was determined that Tanks 1, 2, and 3 should be operated in parallel, and Tank 4 should flow in the opposite direction, used as a completely stirred reactor and final anoxic basin. This will allow a high ORP set point in Zone 4 of each tank, roughly +100 mV, and the nitrogen recycle pump can be operated in each tank. This leads to the seven-times-influent recycle rate, and still allows the feed-forward loop in Tank 4 to function. Figure 2 depicts this proposed mode of operation.

Treatment Results

With the modifications to the wastewater plants operation as described, the wastewater treatment operators are able to achieve effluent with $CBOD_5$ at near 0 mg/l, and TKN in the range of 1.5–3 mg/l with TN from 3–5 mg/l. This is accomplished while delivering only about 3,000 scfm of air to the BNR process during peak events. While the process design equations indicated the recycle rate of 5*Q will yield a finished quality of 6 mg/l nitrate (Ekama, G. et al., 2008), empirical results from testing have shown that recycle rates of 5*Q can yield nitrate in the range of 3 mg/l, which is approximately what has been measured (Pennsylvania Department of Environmental Protection).

The effluent quality may not be possible when the facility's influent levels increase as the nitrogen recycle rate relative to influent will decrease, but it can be close to that number through careful monitoring of the facility. Noted items that must be monitored are the F/M ratio, along with SRT and HRT. Similar results may be possible when flows approach 4.0–4.5 mgd, and it is necessary to add an oxidation ditch as it will be used in series with the BNR. The target ORP values may have to decrease to prevent complete oxygen satisfaction of the treatment process in the BNR, allowing the oxidation ditch to operate at low speed to have both aerobic and anoxic zones present within the treatment process. If there isn't sufficient $CBOD_5$ remaining, the anoxic zone will not be large enough to prevent denitrification in the clarifiers, which can be a serious issue.

Alternatively, the mode of the BNR operation could be operated with Tanks 1 through 3 in parallel, as shown in Figure 2 and described previously. To achieve similar results at a flow of 6 mgd, BNR Tanks 1–3 could run in parallel, with relatively high ORP set points at the west end. This would keep a high recycle rate ([6 mgd*3 Nrcy + 6 mgd RAS]/6 mgd-Q = 4*Q), allowing Tank 4 to operate as an effluent anoxic area with minimal aeration provided early to keep the mixed liquor ORP in the anoxic range and remove nitrogen gas that may still be attached to solids in the process. The oxidation ditches would be utilized as final polishing for additional removal of nutrients, which would require a lower ORP set point in BNR Tanks 1–3 or a late addition carbon source. With the existing oxidation ditches operating, and with a recycle rate of approximately 6 mgd each, the total recycle rate would be approximately 6*Q, or slightly less than the current 7*Q.

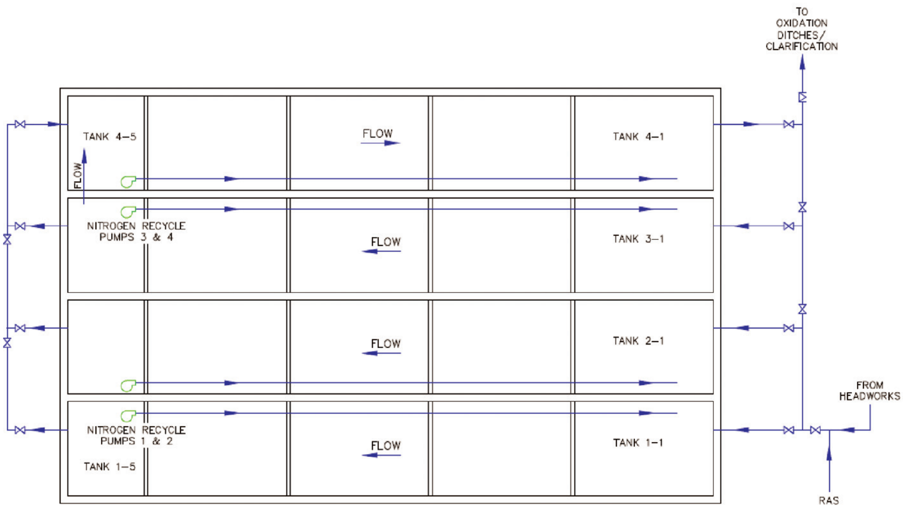

Figure 2. Schematic Layout of Biological Nutrient Removal: Proposed Operational Mode

Potential Startup Pitfalls

One major pitfall of the BNR process at severe underloading can be overaerating. Due to the capability of the BNR process to deliver air far beyond the potential demand, it is easy to overtreat the wastewater early in the BNR, with the remainder of the tank supplying air that is not "demanded" by the organisms present. This can be seen by taking nitrogen profiles. When operated in a series, an early tank, such as Tank 1, may have effluent with nitrates of 6 mg/l and less than 1 mg/l of ammonia going into Tank 2. However, Tank 3 may have ammonia at 2 or 3 mg/l, with nitrates at 12 mg/l. This occurs due to ammonification and, potentially, biological nitrogen fixation, or the ability of bacteria to convert nitrogen gas into ammonia or nitrate. To prevent this, the ORP can be decreased in Tank 1, allowing more ammonia to bleed into the next tank. The process must be more tightly controlled to prevent extremely anaerobic conditions (below -50 mV) from existing in later stage tanks.

Another pitfall is undersizing the initial anoxic portion of the treatment process. If the initial anoxic portion of the treatment process is not calculated, and it is sized too small, it may not be sufficient in size to have meaningful denitrification. For example, attempting to operate Tank 1 with only the first zone of Tank 1 as anoxic, or between 0.1 and 0.15 MG of anoxic volume, resulted in nitrate levels of about 50 mg/l leaving Tank 1. Further, the process had an inability of denitrifying to near the required levels within the process due to depleted $CBOD_5$ in Tanks 2 through 4. This was solved by moving the aeration zones to the west and, further, by operating Tanks 1 through 3 in parallel. By sizing zones properly and keeping track of key operational metrics of a BNR process, startup can quickly be followed by smooth operation.

References

- Goronszy, M.C., Bian, Y., Konicki, D., Jogan, M., and Engle, R., 1992, Oxidation Reduction Potential for Nitrogen and Phosphorous Removal in a Fed-Batched Reactor, Proceedings Water Environment Federation Conference.
- Leschine, S. B., Holwell, K., Canaleparola, E., 1988, Nitrogen Fixation by Anaerobic Cellulolytic Bacteria, Journal Science, pages 1157-1159.
- Metcalf & Eddy, Tchobanoglous, G., Burton, F.L., Stensel, H.D., 2003, Wastewater Engineering: Treatment and Reuse, Chapter 11, McGraw and Hill.
- Ekama, G., Wentzel, M.C., Henze, M., 2008, Biological Wastewater Treatment: Principles, Modelling, and Design, Chapter 5, IWA Publishing.
- Copithorn, 2002, Pennsylvania Department of Environmental Protection, Nutrient Control Seminar, Transparency 64.
- Ott GmbH & Co., 2009, Northeast Regional Wastewater Treatment Facility Expansion, Specific Oxygen Transfer Efficiency Testing Results, Project Submittal.