Process Flexibility: A Key Ingredient In Operational Success

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Nothing is for certain and things change. This adage is true in life and in wastewater treatment. At a wastewater treatment plant, regulations may change, the weather may change, purchased commodities may become more expensive, or the nature of the wastewater influent to the plant may change in unpredictable ways. Only by having the flexibility to adapt can changes be accommodated.

Tampa's Howard F. Curren Advanced Wastewater Treatment Plant began treating to advanced wastewater treatment standards in 1978. The plant on the wastewater side has a capacity of 70 MGD and consists of screening and grit removal, primary treatment, two-stage high purity oxygen (HPO) nitrification, denitrification filters, and chlorination. These facilities have been in operation for over 16 years and have consistently met all permitted effluent limitations, currently 5/5/3. In 1995 the plant effluent averaged 2.0/1.8/2.2.

In 1989, the current expansion project got underway with the goal of expanding the plant capacity to 96 MGD while still meeting AWT standards.

The 70-MGD Plant

Figure 1 shows a diagram of the HPO system. The system was designed as a two-stage nitrification system. Typically, Reactors 1 and 2 operate in the carbonaceous mode and Reactors 4-6 operate in the nitrification mode. Reactor 3 is a swing reactor which can operate in either mode.

Part of the reason for the success of the plant has been the flexibility inherent in the plant design that has allowed operators to adjust to unusual situations and changing regulatory requirements and to operate in ways at times never anticipated. An example of the historic plant flexibility is the capability to change from a two-stage nitrification system to a single-stage system, when summertime high wet weather flows are experienced, by directing the influent to Reactors 1-6. This has allowed the operators to reduce surface overflow rates during wet weather. Due to experience with the 70-MGD plant, even greater flexibility has been designed into the plant expansion.

Figure 1 shows the configuration of the system in both modes of operation. When in two-stage operation the mixed liquor from Reactors 1 and 2 is directed to Final Sedimentation Tank (FST) 1-6. The carbonaceous effluent is returned to the influent of Reactors 4-6 by a pumping station. The nitrified mixed liquor from Reactors 4-6 is directed to FST's 7-12. The nitrified effluent goes on to denitrification filtration.

This works very well under most situations. A low mean cell residence time (MCRT), less than 0.5 days, is maintained in the carbonaceous side and the MCRT in the nitrification side is about 8 days. The average plant BOD load has been about 260 mg/1 and is typically less than 10 mg/1 as it is applied to the filters. With this system, plant operators have been able to handle sustained average BOD values greater than 400 mg/1 while maintaining effluent standards.

The limitation of the two-stage system is that at high flows, the surface overflow rate at the FST's can become excessive. For instance, the average surface overflow rate (SOR) at 60 MGD is 750 gpd/sf. At peak flows it could be as high as 1600 gpd/sf with only 6 FST's available for each stage. This compares to the 800-1200 recommended as the peak hourly SOR in Ten-States Standards. The flexibility has been provided, however, to switch to a single-stage mode of operation when high flows occur. Historically, in Tampa these high flows occur during the summer wet weather period. Summer is also the time when the wastewater temperature is the highest and lower MCRT's are adequate for nitrification. MCRT's of two days and less have been used during the summer single-stage operation periods while maintaining complete nitrification. The flexibility to operate in the single-stage mode has allowed operators to respond to changing conditions.

Other examples of the flexible design aspects are as follows:

- Bypass. The capability to bypass primary treatment to secondary treatment with a portion of the flow has been provided.
- Swing Reactor. The ability to use Reactor 3 in carbonaceous or nitrification modes has allowed maintenance to be performed within the reactors without compromising treatment.
- Deliveries. Methanol can be received in rail cars or tankers and sulfur dioxide can be received in rail cars or ton cylinders. This has allowed plant operators to take advantage of market conditions.

The Expanded Plant

In 1988 planning began for an expansion of the plant to 96 MGD. To minimize cost it was proposed that existing aerobic digesters, which had been phased out, would be used on the wastewater treatment side. These tanks would be used as diffused air reactors and new final sedimentation tanks would be constructed to work in conjunction with the modified tanks. It was determined that about $20,000,000 in construction cost was saved by using the existing tanks.

Following the philosophy which proved successful for the design of the HPO system, it was decided to build in the flexibility to operate in a variety of modes. The expanded plant is now in the final stages of construction.

The new portion of the plant will be capable of being operated in series or in parallel with the existing plant, as shown on Figure 2. In series, the plant will operate similarly to the existing HPO system as a two-stage nitrification plant. The first stage for carbonaceous BOD removal will take place in the existing HPO system, where all reactors will be available for carbonaceous treatment. The diffused air reactors will be for nitrification. The series mode provides the flexibility to operate as a two-stage nitrification system, which has proven successful in the past.

In parallel, the modified tanks will operate as a single-stage nitrification plant with a capacity of up to 26 MGD. The existing HPO system will operate as a two-stage or a single-stage system as necessary, as it does now. The advantage of the parallel mode is the potential of biologically denitrifing in the diffused air reactors to reduce the nitrate load on the filters. The cost effectiveness of this approach will depend on the market price of methanol, but the flexibility allows operators to respond to the market as needed.

Other flexibility features of the biological treatment system include:

- The nitrification pumping station can pump the 96 MGD average and 221 MGD peak flow to the reactors in the series mode or can pump the 26 MGD average and 80 MGD peak flow, as well as 120 MGD of mixed liquor recycle in the parallel mode.
- The incoming wastewater can be applied to the first zone of each reactor for plug flow or to the second zone for step feed. In the case of step feed, the first zone becomes a sludge reaeration zone lowering the solids load on the final sedimentation tanks.
- Anoxic zones are provided upstream in the reactors in the parallel mode for biological denitrification without methanol and downstream in the reactors to allow biological denitrification with methanol in the series mode.

Other flexibility features in the expanded plant include:

- Belt thickeners and gravity thickeners to thicken WAS.
- Collected floating biological solids from the final sedimentation tanks can be thickened separately or in the primary sedimentation tanks.
- Digested and non-digested sludge can be blended to assure that the nitrogen content in the heat dried sludge are at marketable levels.
- Sludge drying beds are maintained as backup to mechanical dewatering and heat drying.
- Sludge storage for digested sludge is being increased to 1.5 million gallons.

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Full-Scale Operational Experience at Ocoee

R. David Holbrook and Robert Holland

The Ocoee, Florida, water reclamation facility has effectively demonstrated that quality effluent levels can be achieved and maintained while minimizing operational costs. Because of the phased mode of operation, nitrification and denitrification take place in the same process volume. Based on influent loading conditions, these phases can be extended or reduced by varying the different phase lengths. The use of automatic dissolved oxygen control in conjunction with submersible mixers has proven to be instrumental in maintaining proper process conditions. Additionally, control and flexibility is achieved through a SCADA system. The system includes extensive real-time and historical trending capabilities as well as on-line assistance for process assistance and maintenance questions.

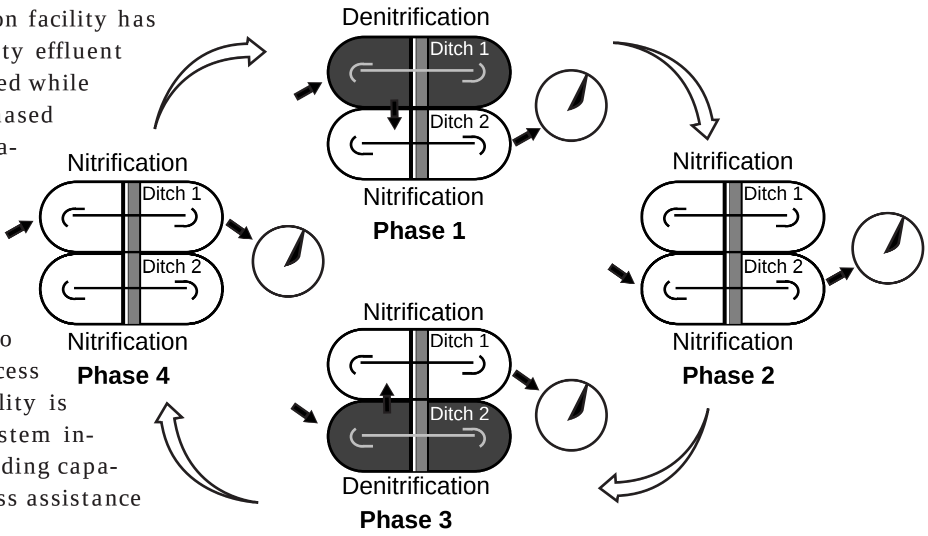

Figure 1. The BioDenitro Process

In the late 1980's, the development status of the phased isolation ditch technology was assessed by EPA, which recommended that "a full-scale demonstration project of the BioDenitro process should be performed in the U.S." in an effort to develop information on overall plant performance. The BioDenitro process is an activated sludge process that utilizes a four-phase operating cycle (Figure 1). The activated sludge reactors are typically oxidation ditches, although the process can be implemented in any type of hydraulically interconnected reactors equipped with separate aeration and mixing equipment as well as influent and effluent controls. The process conditions within the activated sludge reactors are alternated between oxic and anoxic states in order to promote both nitrification and denitrification during the different phases. Upon achieving complete nitrification, anoxic conditions are created in the ditch by ceasing the operation of the aerators and allowing the submersible mixers to maintain the suspension of biosolids.

The four phases of the BioDenitro process allow for significant operational flexibility. Because the process is time dependent rather than volume dependent, the volume allocated for oxic and anoxic conditions can be easily changed (Figure 2). Thus, by varying the phase lengths, the facility can be easily adjusted to meet different loading conditions without sacrificing effluent quality.

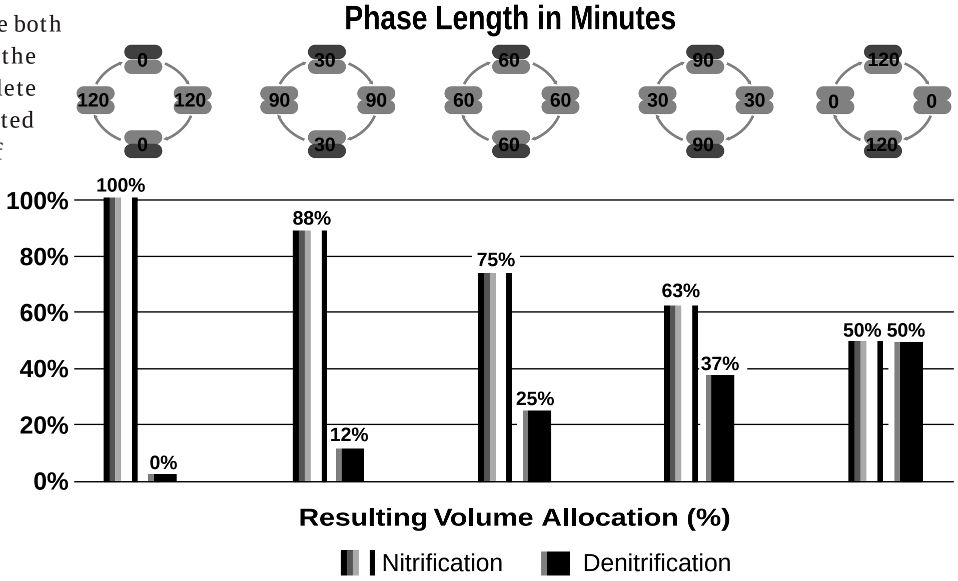

Figure 2. Operational Flexibility of the BioDenitro Process

Beginning operation in June 1994, the 3.0-MGD Ocoee WRF was the first BioDenitro installation in the United States and one of five currently operating in North America, including the University of Florida's WRF, to achieve required effluent concentrations through biological nutrient removal. The influent wastewater undergoes pretreatment consisting of screening and grit removal. The wastewater is then mixed with the return activated sludge and discharged to the oxidation ditches. The Ocoee facility consists of two oxidation ditches with a volume of 1.0 MG each. Each ditch is equipped with two dual-speed 9.0-meter Maxi-Rotors (60/40 HP) and two 9.0-HP POPL-I submersible mixers. Following secondary clarification, the effluent undergoes tertiary filtration, disinfection through chlorine addition, and is stored in a final effluent pond before being reused.

Effluent Results

Because the final effluent is designated for public access reuse sites, strict BOD and TSS effluent concentrations (5.0 mg/L) as well as an effluent nitrate concentration of 12 mg/L is required. The effluent concentrations of BOD and TSS have been consistently below the required limit. The effluent ammo-

Table 1. Average Operating Data (influent/effluent)

Month	Flow MGD	BOD mg/L	TSS mg/L	NH_3-N mg/L	NO_3-N mg/L	Turbidity NTU
June-Dec, 1994	0.82	118/2.4	183/1.0	22/0.5	-/1.0	-/1.0
January, 1995	0.72	136/2.5	190/1.0	16/0.9	—/0.9	—/0.3
February, 1995	0.67	127/2.3	211/1.0	17/0.8~	—/1.0	—/0.4
March, 1995	0.66	108/1.8	187/1.0	19/0.2	—/1.0	—/0.7
April, 1995	0.86	129/2.4	175/1.0	—/0.2	—/0.9	—/0.7
May, 1995	0.86	129/1.5	172/1.0	—/0.2	—/1.0	—/0.5
June, 1995	0.90	133/1.4	186/1.0	24/0.3	—/1.2	—/0.3
July, 1995	1.0	103/2.4	211/1.0	—/1.2	—/0.3	—/0.7
August, 1995	1.2	99/2.4	174/1.0	27/0.2	—/3.6	—/0.3
September, 1995	0.98	107/2.0	174/1.0	—/0.3	—/1.0	—/0.4
October, 1995	0.79	119/2.4	179/1.0	—/0.3	—/2.8	—/0.4
November 1995	0.82	118/2.2	201/1.0	—/0.5	—/1.1	—/0.3
December, 1995	0.89	116/1.7	165/1.0	22/0.2	—/1.4	—/0.3
January, 1996	0.90	136/2.5	190/1.0	16/0.9	—/0.9	—/0.3
February, 1996	0.85	127/2.3	211/1.0	16/0.8	—/1.0	—/0.4
Average	0.86	120/2.1	187/1.0	20/0.5	—/1.3	—/0.5

nia and nitrate concentrations have also been exceptionally low, averaging 0.5 to 1.3 mg/1, respectively, since the plant went on-line (Table 1).

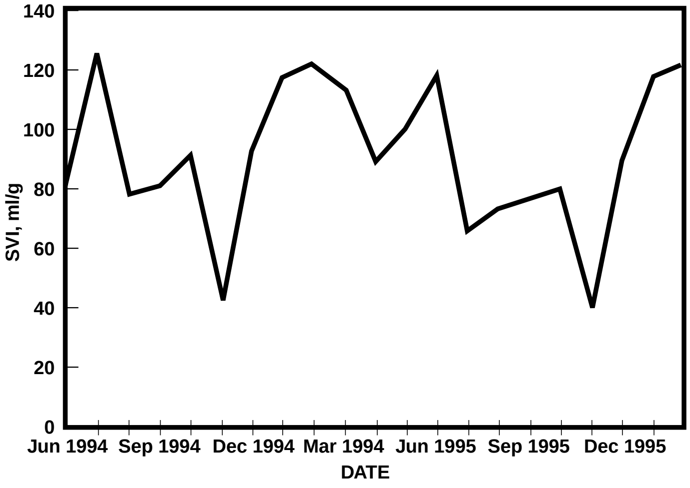

Figure 3. Calculated SVI's

There are several indicators that may indicate that anaerobic conditions are being realized during the later stages of the anoxic phases. The sludge volume index, or SVI, has been averaging approximately 87 mg/l with an average mixed liquor concentration of 2,200 mg/L (Figure 3), which suggests that the growth and proliferation of filamentous bacteria are being severely limited.

Additionally, there appears to be a greater degree of phosphorus removal than typically reported from conventional activated sludge systems. For example, during October, 1994, the average influent or/ho-phosphorus concentration ($PO_{4-}P$) was approximately 4.9 mg/L, while the average effluent concentration was 2.0 mg/L. The average influent BOD concentration during this time was only 95 mg/L, suggesting that excessive phosphorus uptake was realized during this period.

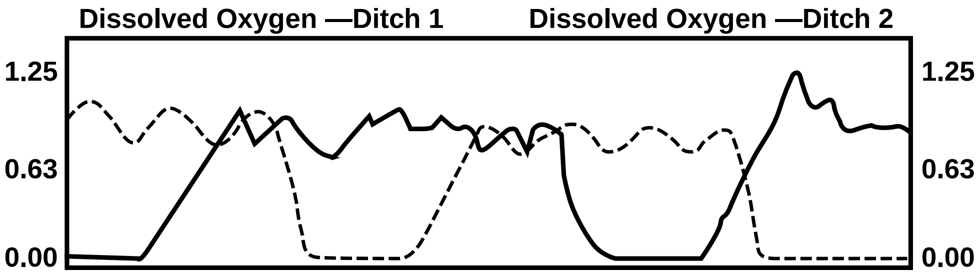

Figure 4. Operating Dissolved Oxygen Concentrations

Automatic Dissolved Oxygen Control

In order to both optimize process conditions and minimize operating costs, the Ocoee BioDenitro system includes automatic dissolved oxygen (DO) control. The rotors are operated to maintain the DO at a pre-determined setpoint. When the DO concentration falls below the setpoint, one rotor will begin operation in low speed. If one rotor cannot maintain the DO concentration above the lower deadband limit, the second rotor will be placed in operation in low speed. Due to the two-speed rotors, a significant amount of aeration flexibility can be realized; the rotors operate in increments of a single rotor in low speed through both rotors operating in high speed.

A typical DO profile is shown in Figure 4. Ditch 1 is the dotted line whereas Ditch 2 is the solids line. The saw-toothed curve is an example of a nitrification phase. When there is no measurable DO, the ditch is undergoing denitrification. During denitrification periods, submersible mixers are maintaining suspension of biosolids. As illustrated from Figure 4, the DO set-point is 0.8 mg/L with a dead band of 0.3 mg/L.

Table 2. Rotor Runtimes during 57-day test period

	Low Speed Runtime (hours)	High Speed Runtime (hours)
Rotor 1	297	157
Rotor 2	368	351
Rotor 3	405	346
Rotor 4	377	210

This level of DO control is significant for the Ocoee WRF. As a result, the carbonaceous and nitrogenous oxygen demands are supplied while virtually eliminating over aeration of the mixed liquor. This will also influence the amount of nitrogen removal realized since any residual DO will have a negative impact on the efficiency of the denitrification phases. Since the process varies between oxic and anoxic conditions, the amount of residual DO contained in the mixed liquor prior to the anoxic phase can be controlled. Additionally, the system can take advantage of any “oxygen credit” from the simultaneous denitrification which occurs during the oxic phases.

Since over aeration is significantly reduced, runtimes of the rotors are minimized. The current operating strategy at the Ocoee WRF includes a nitrification/denitrification allocation percentage of 63/37, respectively. Based on this operational scheme, the total time assigned for nitrification during a 57-day period was 862 hours. The average runtimes the rotors operated at slow and fast speeds were 362 and 266 hours, respectively (Table 2). Therefore, the rotors operated only 42 percent in low speed and 31 percent in high speed of the total assigned nitrification time, resulting in increased energy savings.

The discrepancy in the runtimes between each of the four rotors can be explained by the differences in the operating levels of the two oxidation ditches. By adjusting the automatic effluent weirs, the submergence of the rotors can be varied which translates into different oxygen transfer efficiency. By raising the automatic effluent weir, the submergence on the rotor is increased which increases the amount of oxygen transferred per unit foot of rotor.

SCADA System

The SCADA system at the Ocoee WRF is a PC-based system which monitors and controls the BioDenitro process and stores the relevant data used to compute and report plant performance. Within the system, each operator is assigned a unique password which provides certain levels of access. The dynamic real-time displays detail the running or alarm state of the equipment in addition to updating the various flows, levels or positions of the fluctuating process conditions.

In addition to starting or stopping various pieces of equipment, the operators may change different parameters which allow various control loops to be optimized. The graphic displays feature on-line help which provides detailed process, operations and maintenance assistance for the various pieces of plant equipment.

The system stores all alarms and events for the plant processes. When an alarm occurs, the operator is immediately notified via audible alarm and pop-up alarm screen on the graphic display. The alarm popup screen will appear regardless of which display the operator is viewing. At the same time, the plant alarms are sent to alpha-numeric pagers which relay all important information regarding the alarm condition.

The information collected by the SCADA system is stored in historical data files to be reviewed, up to four variables at a time, by plant personnel. The time span and process variable range may also be selected allowing the operator to zoom on specific data. All real-time information is linked automatically to manually entered laboratory data to create pre-formatted water quality and accountability reports. These reports are sent to the State of Florida each month.

Due to the stability of the BioDenitro process and the level of control and monitoring performance of the SCADA system, the Ocoee WRF has been able to reduce their on-site operational shift time from 16 to 8 hours.

Summary

The BioDenitro process consistently produces a high quality effluent; the effluent nitrate concentration has averaged below 2 mg/L. This level of effluent quality is done biologically and with no supplemental chemicals. Additionally, the automatic dissolved oxygen control in conjunction with submersible mixers has been used effectively in controlling optimal process conditions as well as minimizing operating and maintenance costs. The SCADA system has been used as a valuable tool in tracking plant performance by monitoring the status of equipment, and generating the required reports. Due to the flexibility and reliability of the BioDenitro process and integrated controls, the time required of an on-site operator at the Ocoee WRF has been significantly reduced.

References

1. Tetrault, M.J., Rusten, B., Benedict, A.H., and Kreisel, J.F., Assessment of Phased Isolation Ditch Technologies. Journal WPCF, Volume 59, No. 9, September 1987.

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