Dissolved Oxygen Control Based in Real-Time Oxygen Uptake Rate Estimation

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Producing a stable aeration control system requires that system disturbances be qualified and processed, and that a measured and appropriate control action be provided. Typical Proportional-Integral (PI) control systems use cascade PI control methods, which directly respond to the system's dissolved oxygen (DO) reading to control valves and blowers. However, these control algorithms often undershoot and overshoot their respective DO set-points due to the systemic limits PI feedback control systems have for processing disturbance information. The PI control systems are typically tuned to enact a specific magnitude response to an observed process disturbance. As the system's loading and oxygen uptake rate (OUR) change, so must the nature of the response in order to provide an appropriate control action. Thus, PI loops require frequent retuning to allow the controller to adapt to the new conditions. Unfortunately, retuning is an involved and often troublesome process, which often requires systems to be placed into a manual or offline state if proper step response analysis PI tuning methods are to be practiced. Many PI control systems in effect today have been manually tuned by experienced supervisory control and data acquisition (SCADA) technicians; however, in many cases these manually tuned controls have not been optimized by engineers who more completely understand the process to be controlled and the control theory and proper tuning methods available, causing these PI loops to often fail in automating their processes to the fullest capacity.

The continuous operational nature of wastewater treatment plants necessitates a continuously self-correcting control algorithm, which can respond to constantly changing plant conditions, such as the OUR of the mixed liquor, and has led to the development of the model-based control system discussed here. The described system focuses on determining and providing the required air flow rate to reach or maintain the DO set-point for each aeration zone, and then adjusting the valve position set-points simultaneously to achieve the desired air flow rate for each zone.

The aeration control system has been tested using a Matlab-powered International Water Association (IWA) benchmark model against a typical auto-tuned PI aeration system under normal Modified Ludzack-Ettinger (MLE) operating conditions. The aeration system has also been installed and tested at Poinciana Water Reclamation Facility (WRF) No. 2.

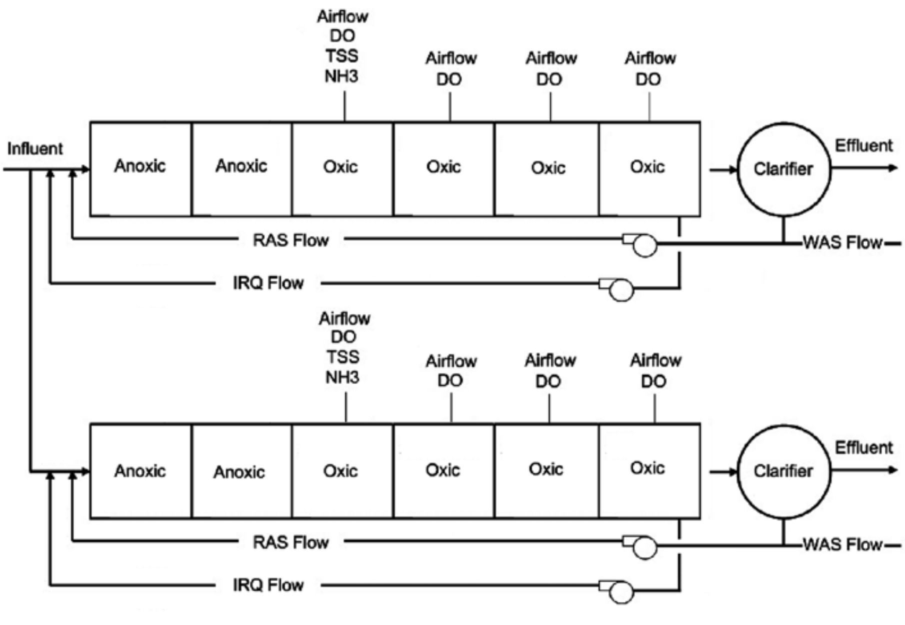

Figure 1. Process Flow Diagram of Poinciana Water Reclamation Facility No. 2

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Poinciana Water Reclamation Facility No. 2: Plant Profile

The Poinciana WRF No. 2 is a 6-mgd activated sludge treatment plant located in Polk County that treats domestic wastewater from residential sources. Existing major treatment units consist of grit and mechanical screening, activated sludge reactors, final clarifiers, sand filters, chlorine contact tanks, an effluent pumping station, a reclaimed water reuse system, and percolation ponds. The sludge processing for this facility is located off-site.

The diagram of the secondary treatment process as shown in Figure 1 depicts a traditional MLE-type process. There are two identical trains (train A and train B) with an influent flow splitter between them. Each of the trains consists of two anoxic basins, four aeration basins (with the last aeration zone being utilized as a re-aeration basin), and two final clarifiers.

The aeration system consists of a total of three positive displacement blowers controlled by variable frequency drive (VFD), each having an approximate capacity of 2,400 standard cu ft/min. The aeration system is piped so that both trains are on the same air header. Each aeration zone is configured as a control zone and is equipped with a DO probe, a modulating-duty automated air control valve, and an air mass-flow meter. The main header exiting the blower building is outfitted with one total air mass flow meter, which a PI control loop utilizes for blower VFD regulation.

The plant's influent flow demonstrates large irregular spikes throughout the day due to the pump-fed nature of the collection system. This system necessitates the application of a robust and accurate DO control system in order to maintain a stable process, meet effluent goals, and realize energy cost savings.

Methodology

A challenging aspect of providing a stable and robust aeration control system is the proper rejection of process disturbances, which are, in the case of wastewater treatment, changes in loading and operating conditions, such as biochemical oxygen demand (BOD), NH_4, flow rate, temperature, and mixed liquor suspended solids (MLSS).

The proposed process-based control system uses DO readings and airflow rates in each aeration (control) zone to calculate a factor that is representative of the biological activity in the control zone. This feedback control method calculates OUR by measuring the DO response to the airflow rate over the last control cycle. By trending this OUR information, one can predict if the loading conditions are increasing, decreasing, or staying the same, and make an appropriate control response based on the predicted OUR over the next control cycle to determine an airflow set-point.

The control algorithm's primary output is an air mass-flow set-point for each aeration zone. The control sums up each zone's airflow set-point and provides this total airflow set-point to a blower control system. After sufficient time has been given to the blower system to adjust to a given total airflow set-point, "flow coefficient to valve position" calculations unique to each valve are utilized by the described control system to provide an approximate valve position set-point for each automated control valve. This algorithm runs in an iterative fashion every few seconds until a final valve position solution has been converged upon, at which point the calculations cease and an iterative nudge-open/nudge-close airflow-based feedback loop activates to provide minor final adjustments to the valve positions. After giving the valve control logic a sufficient amount of time to attempt to adjust to the desired airflow, the valves lock into a final position to prevent unnecessary additional starts of the actuator for the remainder of the control cycle.

When a new control cycle begins, the air flow set-point is recalculated—the valve lock out is lifted and the control logic restarts. The valve position control also incorporates "most open valve" (MOV) logic into its algorithm, which keeps blower load down and efficiency high by focusing on keeping system pressure low. This is accomplished by ensuring that at least one of the larger valves in the system is constantly held in an almost completely open position, adjusting other valves to either pull air away from or push air to the most open valve. As the system operates, the MOV can migrate between the zones according to whichever had the highest demand for air as the day progresses.

This approach to controlling valves, in addition to being formulated to improve the valve's response to track new airflow set-points by introducing intelligence to typical feedback control systems, is also expected to extend the operational life of valve actuators by limiting the number of starts, and hence providing for less wear than a typical PI control system.

Testing the feasibility of this control theory involves modeling a benchmark simulation using the activated sludge model (ASM) and

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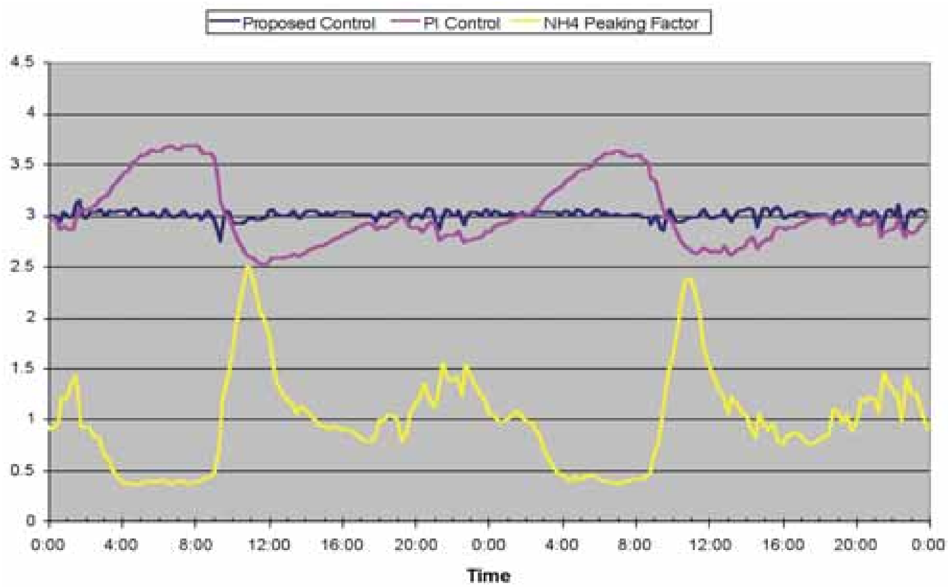

Figure 2. Proportional-Integral Control vs. Proposed Dissolved Oxygen Control Simulation

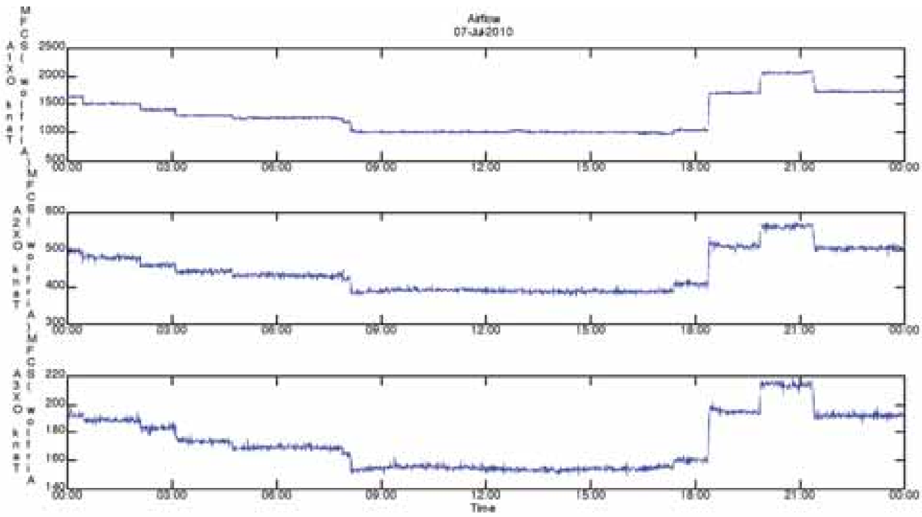

Figure 3. Airflow Profile of Plant Under Manual Control

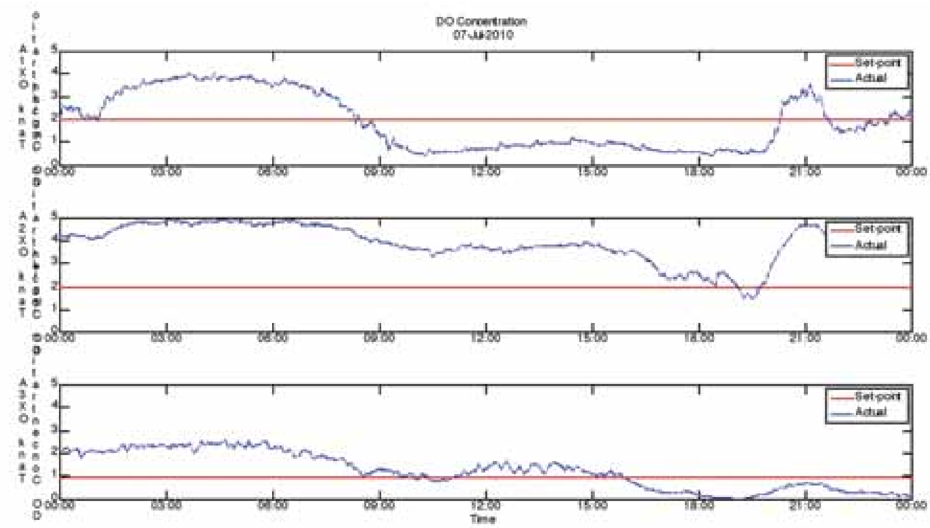

Figure 4. Dissolved Oxygen Profile of Plant Under Manual Control

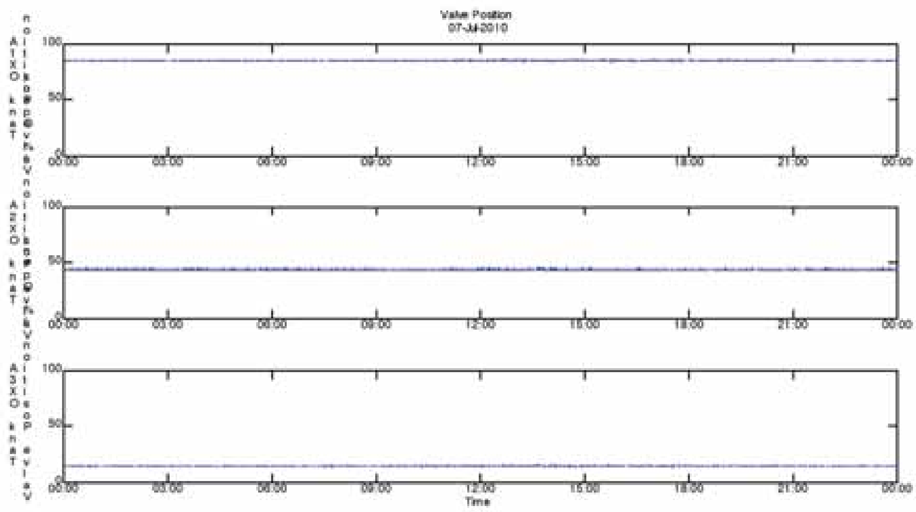

Figure 5. Valve Position Profile of Plant Under Manual Control

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enacting the proposed control methods. In this case, model number 1 (BSM1), (Copp, 2002) was plugged into an ASM simulator generated in Matlab to compare the proposed control method to a traditional PI control loop. The model was configured to use dry weather conditions and a denitrification layout.

Applying this control at Poinciana WRF No. 2 includes tying in a programmable logic controller and industrial PC containing the proposed control logic into the plant's SCADA system. This hardware provides the total airflow and valve position set-points to the SCADA for implementation and receives DO, valve position, and measured airflow values for each aeration zone.

Results

Simulation Results

Figure 2 depicts the results of the comparison between the proposed control method and a typical PI control method. The NH_4 peaking factor in the graph is indicative of loading changes over the 48-hour period. Note that the PI control tracks the DO set-point; however, it exhibits typical PI overshoot and integral windup behavior resulting in oscillation about the set-point. Note also how the proposed control model is able to adjust to the loading without needing to experience an error signal from the modeled DO sensor.

Poinciana Water Reclamation Facility No. 2: Plant Install Results

The Poinciana WRF No. 2 aeration system has been automated using the proposed control on its one active process train since early 2010. The first set of figures provides a snapshot of a typical day controlled by manual adjustments to the valves and air blowers by plant operators. Figures 3, 4, and 5 compare the airflow, DO vs. DO set-point, and valve position of the automated control valve for each of the first three zones where the plant has disabled the aeration control system in favor of manual control.

During the test period, only train A was running, so operators opened and closed air valves on train B throughout the day in order to keep these systems from going septic; this caused very large drops and spikes in airflows provided to train A. The best evidence of such an event can be found in figure 3, between the times of 8:00 and 9:00, when the valves to train B were opened causing the airflow rates to train A to drop, and between the times 18:00 and 19:00, when the valves to train B were closed and the airflow to train A was restored, causing the airflow rates to rise. Figure 4 also provides evidence of a more typical type of system disturbance depicting a characteristic rounded off peak and dive of the DO reading between the hours of 6:00 and 10:00, a pattern related to and typical of normal diurnal flow and loading.

The second set of figures provides insight into how the automated aeration control system compensates for these and other disturbances in an attempt to maintain a steady DO set-point. Figures 6, 7, and 8 compare the airflow, DO vs. DO set-point, and valve position of the automated control valve for each of the first three zones while the control is active.

Figure 6 demonstrates that as the load increases between 15:00 and 17:00, the system responds by raising airflow levels. The result, shown in Figure 7, is a DO reading, which across each tank deviates from set-point on average by less than 0.5 mg/L. The largest deviation is observed in the first oxic zone, as this is the zone which first receives the full brunt of increased oxygen demand due to the lack of a primary clarifier. Also to be noted at the time period between 5:00 and 6:00 is that the valves to train B are opened, as can be seen with the downward 'blip' of airflow in each zone just before 6:00. The proposed control compensates for this almost immediately and prevents this disturbance from affecting the DO of each zone by increasing the total airflow set-point to compensate for the airflow lost to train B.

Figure 8 demonstrates the system's MOV logic. In this case, the MOV is in zone 1, leaving zones 2 and 3 active to push and pull air away from the MOV zone. The determinative valve control also prevents valve hunting and unnecessary valve starts as demonstrated by long periods of steady position, as intended.

Conclusions

Based on these results, the proposed aeration control system has demonstrated robust and accurate DO set-point tracking at Poinciana WRF No. 2. The MOV control logic has performed as intended in limiting valve actuations to far below manufacturer limits, but more data must be collected before it can be determined if this will actually increase the lifespan of the valves. According to simulations, the proposed control method outperforms traditional PI controls and its successful application in the field has confirmed its proof of concept. Long-term testing is required to determine if applications of this control provide operational and maintenance cost benefits to plants with a need for tight DO regulation.

References

- Copp, J.B. (2002) *The COST Simulation Benchmark: Description and Simulator Manual*; ISBN 92-894-1658-0; Office for Official Publications of European Communities: Luxembourg.

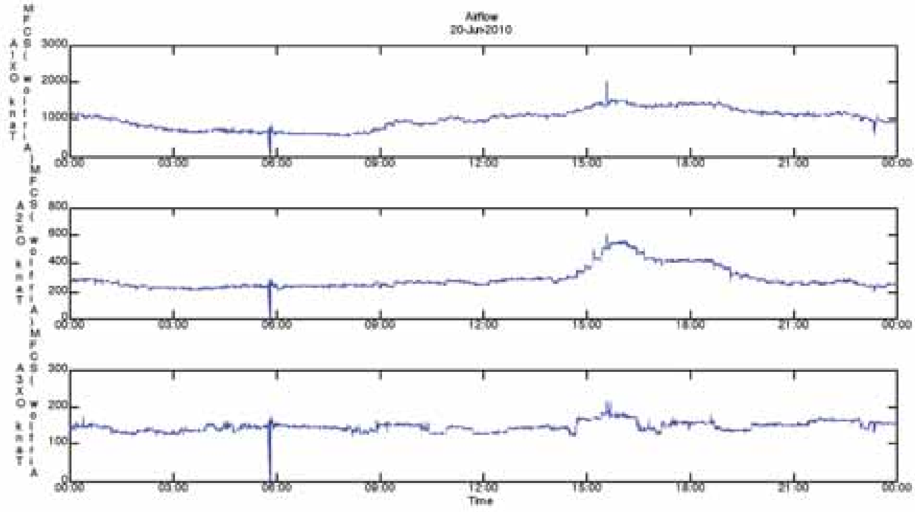

Figure 6. Airflow Profile of Plant Under Automatic Control

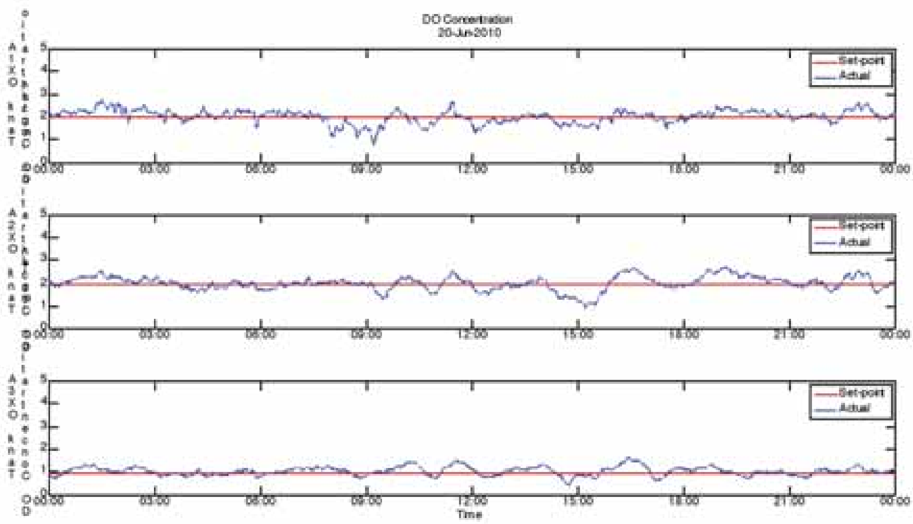

Figure 7. Dissolved Oxygen of Plant Under Automatic Control

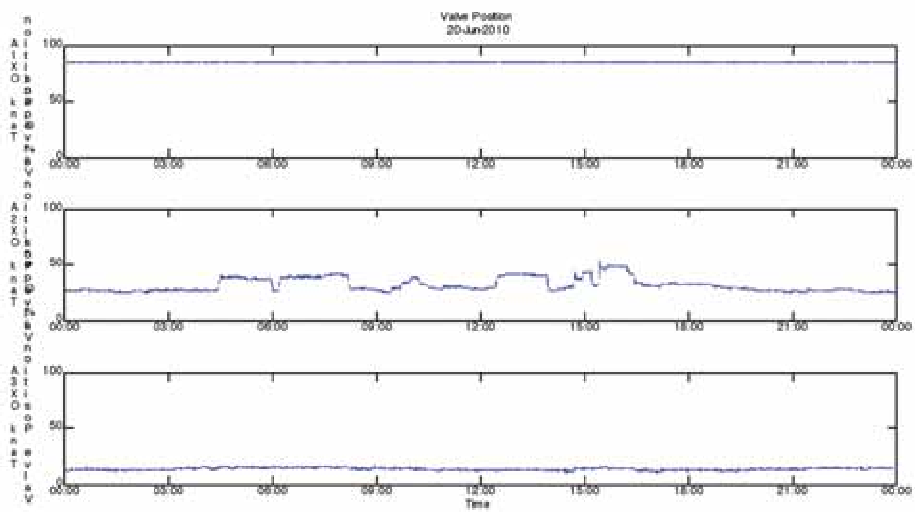

Figure 8. Airflow Profile of Plant Under Automatic Control