DISSOLVED OXYGEN CONTROL BASED ON REAL TIME OXYGEN UPTAKE RATE ESTIMATION

Gregory Duffy, Steven Kestel, Matthew Gray, George Lee, Tilo Stahl, Jim Zhang
BioChem Technology, Inc, 3620 Horizon Drive, Ste. 200, King of Prussia, PA, 19406, USA

ABSTRACT

The ammonia loading model-based feed-forward aeration control system outlined herein shows more robust process disturbance rejection than traditional PI control methods, resulting in overall improved process efficiency and decreased mean time deviation from DO set point. Control methods are discussed and verified through simulation and practical application at Poinciana Water Reclamation Facility No. 2 located in Polk County, Florida.

KEYWORDS

Process Control, Instrumentation, Feed-forward, Automation, Dissolved Oxygen, Aeration

INTRODUCTION

Producing a stable, comprehensive aeration control system mandates that system disturbances be processed, qualified, and taken into consideration when intending to provide a measured and appropriate control action. Typical 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 control systems have for processing disturbance information. 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 rates change so must this measured 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 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 effectively manually tuned by experienced SCADA technicians; however in many cases these manually tuned controls have not been optimized by professional controls engineers who more completely understand the control theory and proper tuning methods available causing these PI loops to often fail in automating their processes to their fullest capacity.

The continuous operational nature of waste water treatment plants necessitates a continuous self correcting control algorithm which can respond to constantly changing plant conditions, such as the Oxygen Uptake Rate of the mixed liquor, and has lead to the development of the model based control system discussed herein. The proposed control system focuses on determining and providing the required air flow rate to reach DO set point for each aeration zone and then adjusting the valve position set points simultaneously to achieve this desired air flow rate for each zone.

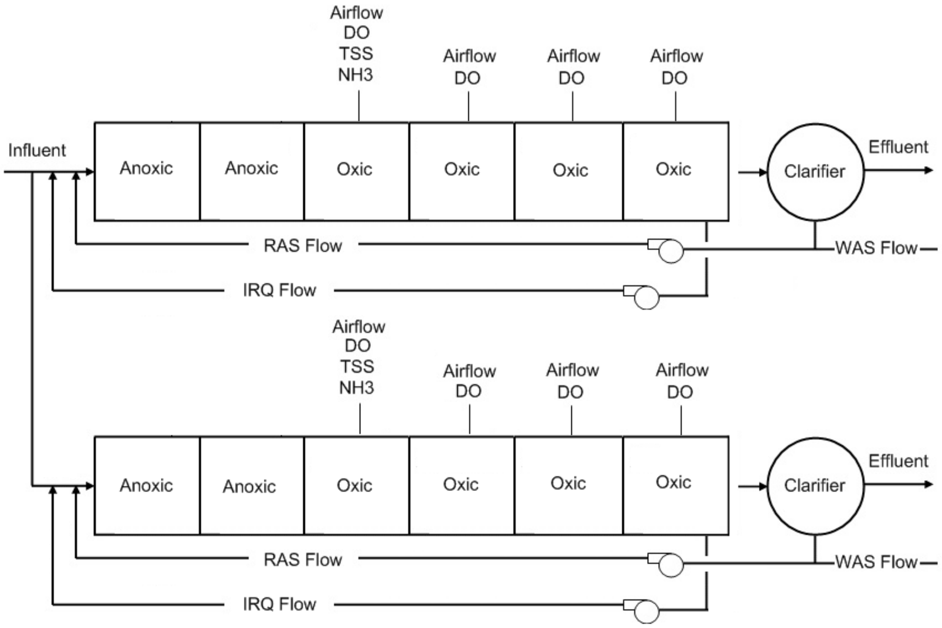
The aeration control system has been tested using a Matlab powered IWA benchmark model against a typical auto-tuned PI aeration system under normal MLE operating conditions. The aeration system has also been installed and tested at a newly upgraded water reclamation facility, Poinciana Water Reclamation Facility (WRF) No. 2.

Poinciana WRF No. 2 – Plant Profile

Poinciana WRF Plant No. 2 is a 6 MGD activated sludge treatment plant located in Polk County, Florida, 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 offsite.

A diagram of the secondary treatment process is 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 each train. Each of the trains consists of 4 aeration basins, two anoxic basins, with the last aeration zone being utilized as a re-aeration basin, and two final clarifiers.

Figure 1: Process Flow Diagram of Poinciana No. 2



The aeration system consists of a total of three PI loop VFD controlled positive displacement blowers; each having an approximate capacity of 2,400 SCFM. The aeration system is piped so that both trains are on the same air header with each zone outfitted with it's own remote controlled automated control valve and air mass-flow meter; the main header exiting the air 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 in influent flow throughout the day due to the pump fed nature of the collection system. Under normal operating conditions, a dynamic DO set point plant optimization control is utilized to reduce the plant's energy footprint; this system necessitates the application of a robust and accurate DO set point tracking aeration control system in order to realize these 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 waste water treatment, unpredictable loading conditions. Therefore, the most direct way to accomplish the goal of optimizing such a process, is to first quantify the influent load by strategically locating ‘loading sensitive’ *in-situ* instrumentation at the beginning of (or directly before) the first oxic zone and then preemptively responding to this information before the load disturbs the oxic zones’ DO reading. Because an accurate BOD/COD loading measurement cannot be collected in real time, an online ammonia analyzer can be utilized as an indirect indicator of BOD/COD loading. To do this, first one must correlate BOD/COD concentrations with ammonia concentrations throughout the day. Tests on the influent for both BOD/COD and ammonia concentrations performed at different points throughout the day allow for the establishment of such an approximate proportional relationship.

Once an estimate for the current oxygen demand of the influent is gauged, this information is processed by an algorithm based on the Activated Sludge Model (ASM) to estimate the current OUR and the proper airflow rate required to correctly compensate to any changes in the OUR in the incoming wastewater since the last control cycle. In the event that the ammonia signal is low quality or lost due to equipment failure, the system’s backup control formulates the proper control response by applying an advanced feedback control method. 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 off the predicted OUR over the next control cycle to determine an airflow set point.

Regardless of which method is being currently utilized by the plant, 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 configured to track a given air flow set point – in the case of Poinciana No. 2, a PI controller. After sufficient time has been given to the blower system to adjust to a given total airflow set point, 'Flow Coefficient (Cv) to valve position' calculations unique to each valve are utilized by the proposed 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 in to a final position to prevent unnecessary additional starts of the actuator for the remainder of the control cycle. When a new air flow set point is calculated – 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 a nearly completely open position, adjusting other valves to either pull air away from or push air to that 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, also is 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 and 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 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 influent ammonia measurements for each train and DO, valve position, and measured airflow values for each oxic zone.

RESULTS

Simulation Results

Figure 2 depicts the results of the comparison between the proposed control method and a typical PI control method. Note that the PI control tracks the DO set point, however exhibits typical PI overshoot and integral windup behavior resulting in oscillation about the set point. Note how the proposed control model is able to adjust to the loading without needing to experience an error signal from the modeled DO sensor.

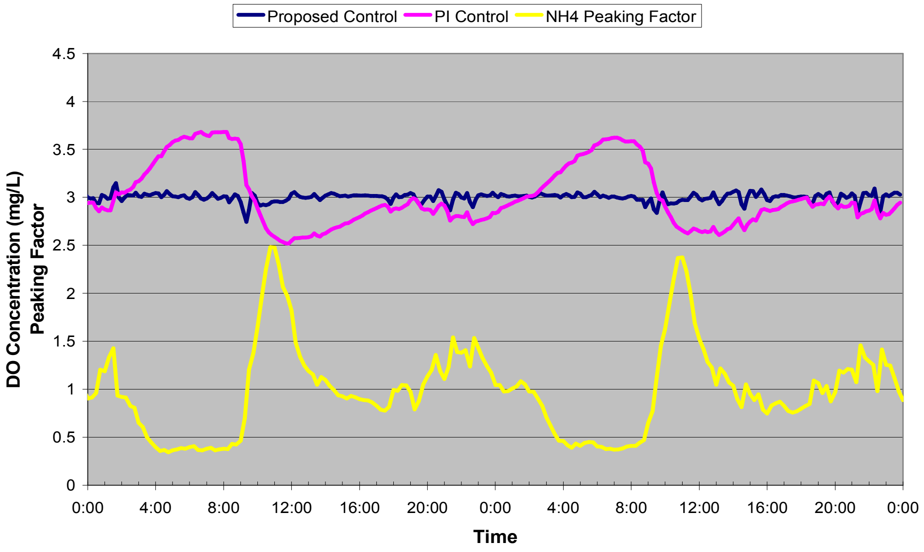


Figure 2: PI control vs. Proposed DO control simulation

Poinciana No. 2 – Plant Install Results

Poinciana No. 2's aeration system has been automated by the proposed control on its one active process train since early 2010, using the backup OUR trending method due to instrumentation issues on the first three oxic zones. 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 while the plant has disabled the aeration control system in favor of manual control.

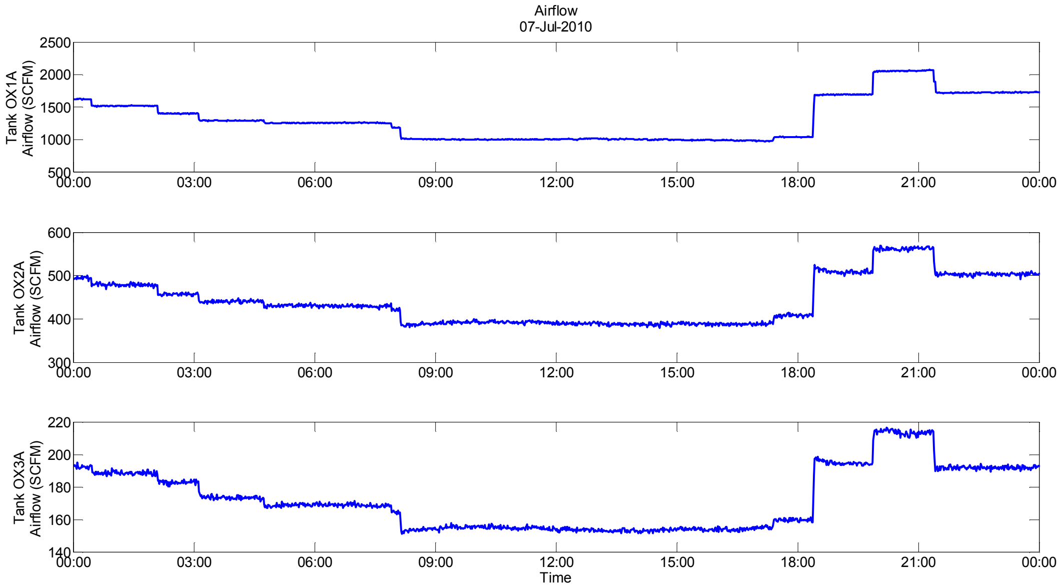


Figure 3: Airflow Profile of Plant Under Manual Control

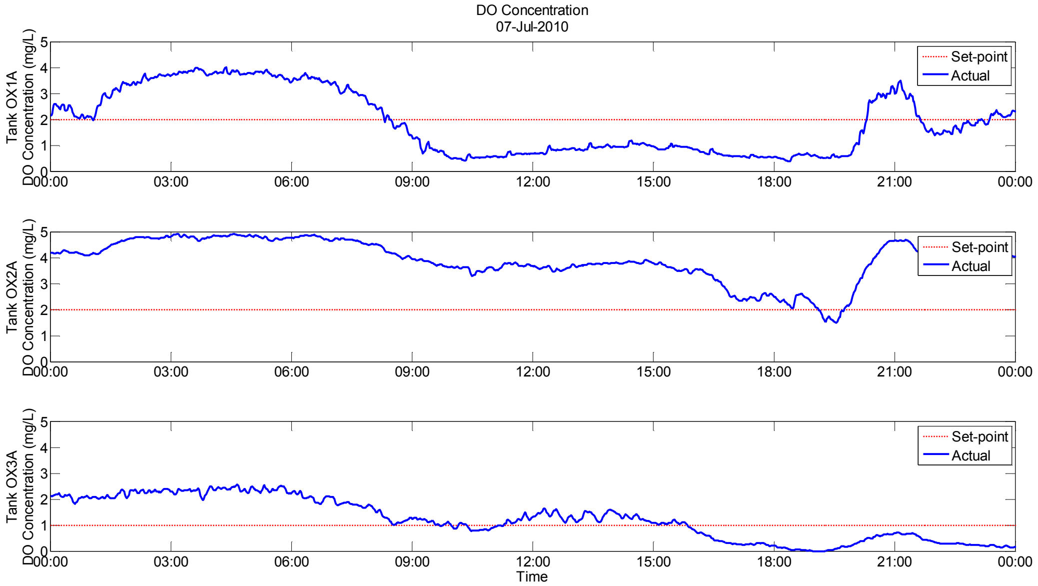


Figure 4: DO Profile of Plant Under Manual Control

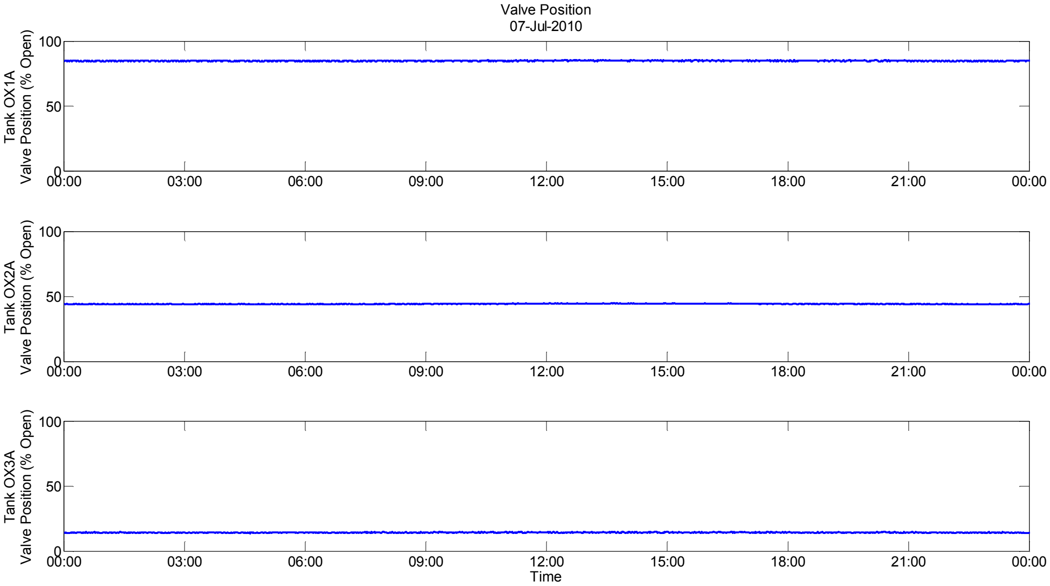


Figure 5: Valve Position Profile of Plant Under Manual Control

One of the more serious disturbances unexpectedly experienced at this plant include that because only Train A is running, operators throughout the day open and close air valves on Train B in order to keep these systems from going septic – this causes very large drops and spikes in airflows provided to train one. 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 are 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 are closed and the airflow to Train A is 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 intrinsic to normal diurnal flow.

This second set of figures below 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.

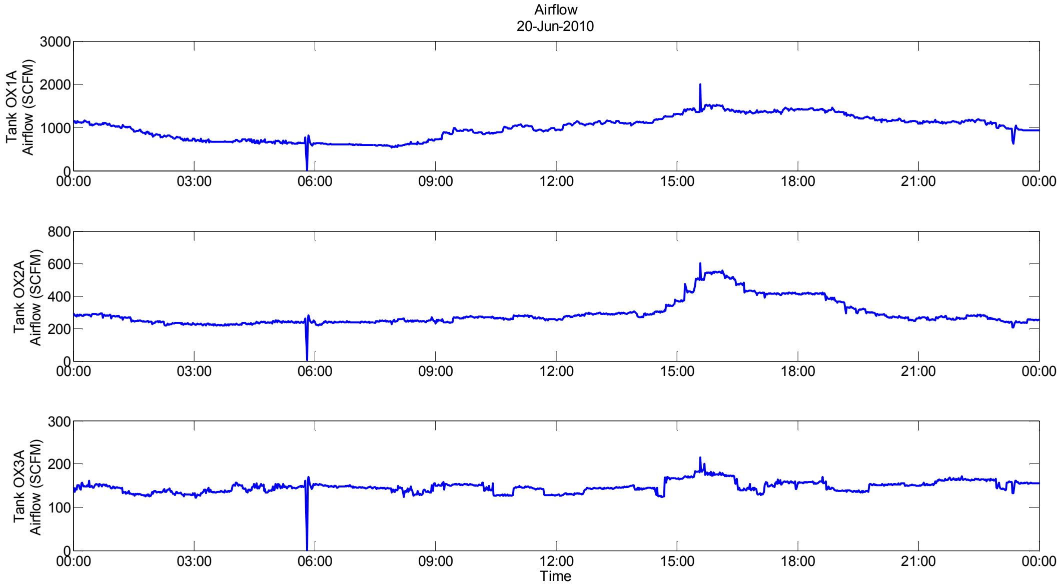


Figure 6: Airflow Profile of Plant Under Automatic Control

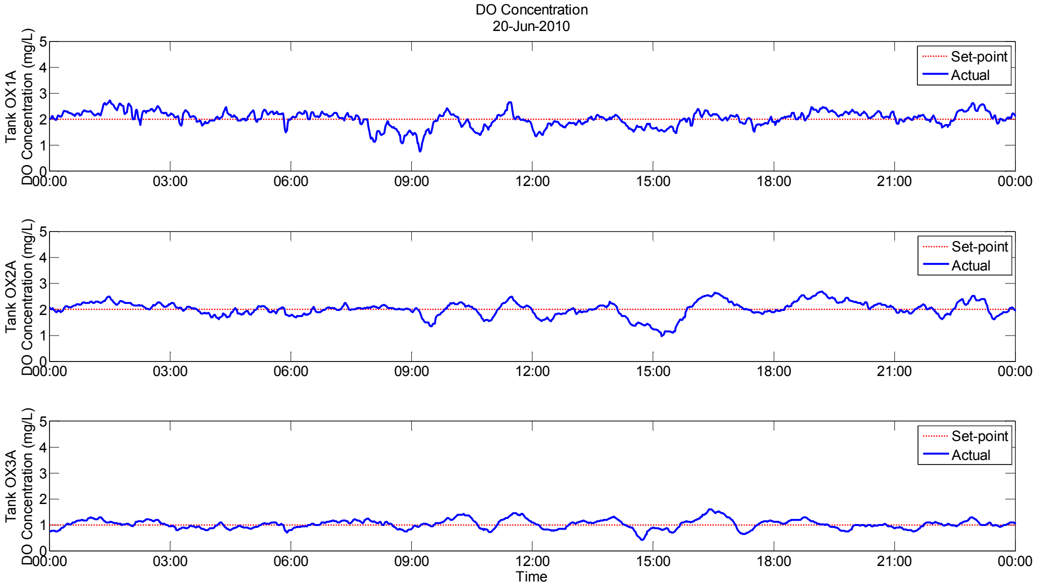


Figure 7: DO of Plant Under Automatic Control

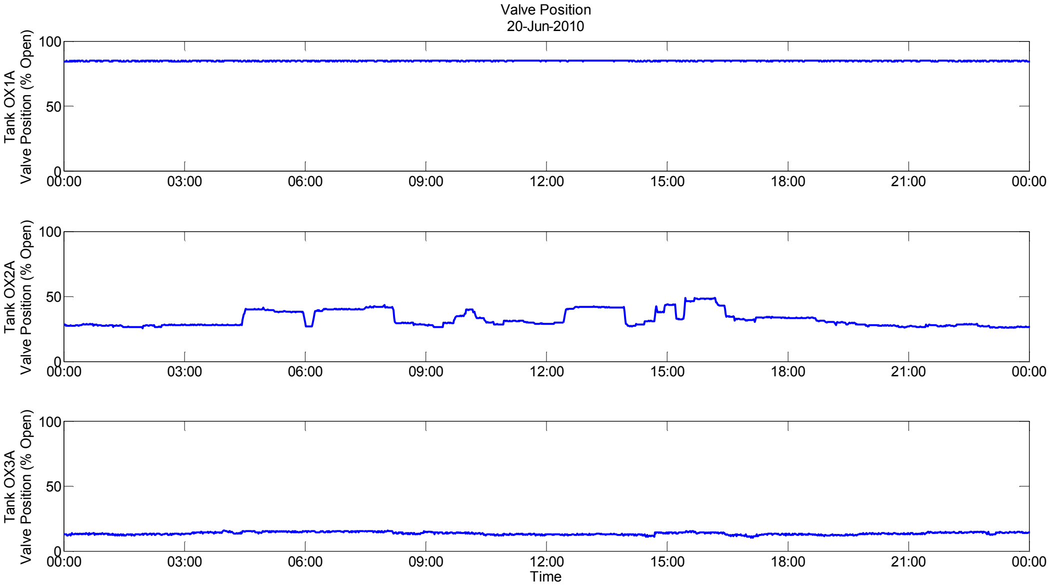


Figure 8: Airflow Profile of Plant Under Automatic Control

Figure 6 demonstrates that as the load increases between 15:00 – 17:00, the system responds by raising airflow levels to compensate. 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 most deviation being 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 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 No. 2 by utilizing the backup non-ammonia signal based control method. More time and data are required in order to test the theoretical benefits of utilizing the ammonia based feed forward control in an actual plant environment. The MOV control logic has performed as intended in limiting valve actuations to far below manufacturer limits, however 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 benefit 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: Lexembourg.