IMPLEMENTING AN AERATION CONTROL SYSTEM AT THE BIGGEST WWTP IN CHINA

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ABSTRACT

In recent years, China has begun to reap the benefits of installing and operating automatic process control systems in wastewater treatment plants. Multiple case studies have demonstrated that an advanced model based control system may not only assist wastewater treatment plants in meeting more stringent effluent permits, but also lead to improvements in process stability and energy savings. To achieve these benefits and ensure the plant is operating at peak efficiency, Bailonggang Wastewater Treatment Plant (WWTP), located in Shanghai, China, has opted to employ an advanced model based aeration control system in its most recent expansion which added 212 MGD of capacity to the existing capacity of XXX. This paper presents a full case study of the process of designing and commissioning an aeration system based upon variable oxygen uptake rate and discusses the typical issues which arise while implementing such a system in such a large scale application.

KEYWORDS

Aeration control, process optimization, nutrient removal, feed-forward control, energy saving, dissolved oxygen (DO) control, blower control.

INTRODUCTION

With continuing increases in energy costs and the requirements of biological nutrient removal (BNR), process control has become one of the most important components of the operations of activated sludge processes and also the most significant approach for achieving energy saving while controlling the aeration blower system.

A well designed and implemented process control system is able to save significant amounts of energy since the aeration system for a typical activated sludge process often accounts for approximately 50% to 60% of the total energy use of the plant (EPA, 1989). A process control system can also be able to maintain a good process chain in order to respond to the disturbances seen by wastewater treatment plants (WWTPs). For a typical municipal WWTP, it faces its influent loading unstable for days, months and throughout the year. The loading could vary in flow, concentration and even the composition. The WWTP must still maintain consistent effluent quality despite these fluctuations. A process control system with proper instrumentation will minimize the effect of diurnal and long-term fluctuations on the effluent quality while achieving treatment goals.

For a WWTP with the activated sludge process, the popularity of having dissolved oxygen (DO) control has been increasing with the rising cost of energy and the emergence of better online instrumentation. It starts with the fixed DO set-points control and then dynamic DO set-points has revealed its advantages and potential to have more stable process control ability and also gain the greater energy saving. Successful implementation can provide aeration energy savings of 10% to 20% while maintaining good effluent quality for a WWTP.

For the dynamic DO set-points control, there are two different control principles which are feed-forward and feed-back. Feed-forward control requires extra on-line instruments installed at the aeration tank such as ammonia and nitrate analyzers to detect the influent concentration so that the process control system would be able to adjust DO set-points before having the liquid coming through. In order to track those dynamic DO set-points, different control methods have been used in the past. PID control is the most popular one method, but it also has shown a disadvantage of operating the equipment too often while controlling. To prevent a new technique to control air valves by introducing the CV calculation in order to minimize the valve actionswas used.

Based on the requirement to provide consistent effluent that met the discharge standard and to pursue possible energy savings, Bailonggang WWTP, China, decided to install one full set of the process control system with feed-forward dynamic a DO set-point calculation function and also the aeration control ability to automatically control the blower system and air valves.

Shanghai Bailonggang WWTP, China – Plant Profile

Shanghai Bailonggang WWTP is in the process of being designed and built in a series of phases. Currently, this plant is responsible for serving an area of 105 mi^2 (272 km2) and a population of 3.56 million. Total flow to the plant is expected to reach 951 MGD by 2020. Phase I of the plant has a design capacity of 528 MGD, which was reached in 2008.

Figure 1. Aerial View of the Bailongang WWTP

Planning for a Phase II expansion project began in early 2010 and the expansion fully operational with a capacity of 212 MGD in April 2014. The secondary treatment process for Phase II consists of eight identical trains in an anaerobic-anoxic-oxic (AAO) configuration. A diagram of one train can be found in Figure 1 which indicates DO control zones, air pipes and the installation positions for analyzers and other equipment.

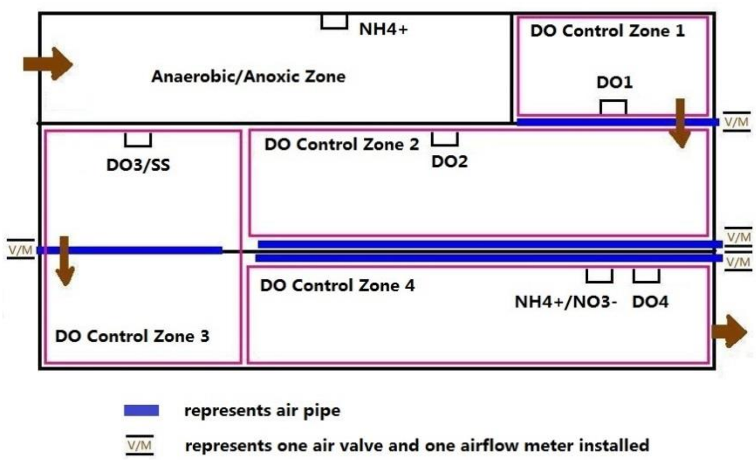

Figure 2: Layout of One Aeration Train and Installation Positions for Instruments

METHODOLOGY

Control Theory

Wastewater treatment plants (WWTPs) do not typically run at design conditions during most of the day, most of the year, and lifetime of the plant, which provides room for having operation optimized. The aeration system of an activated sludge process typically consumes the highest energy during the whole treatment process, usually more than 50% of the total. Thus, implementing an aeration control system using dynamic DO set-points would be able to lower the energy consumption of the aeration system while having variable influent loading to a WWTP.

The purpose of calculating and tracking dynamic DO set-point is to meet effluent ammonia targets while minimizing the amount of oxygen supplied to the process. Minimizing the supplied oxygen reduces the loading on the air blowers, resulting in significant energy and monetary savings.

Residual DO in each aerobic stage of the process can be used to control the specific nitrification rate of the biomass. Increasing the DO concentration increases the nitrification rate by increasing the availability of oxygen to the autotrophic biomass. The increase in the nitrification rate results in a decrease in the effluent ammonia concentration. The converse is also true; lowering the DO concentration will increase effluent ammonia.

Feed-Forward Process Controller Description

The Feed-Forward Process Controller is a combination of two control systems. One is a model-based process controller and the other is an aeration control system. This systemhelps the plant control the BNR process properly and automatically. Figure 3 is a diagram that visually explains the feed-forward process controller.

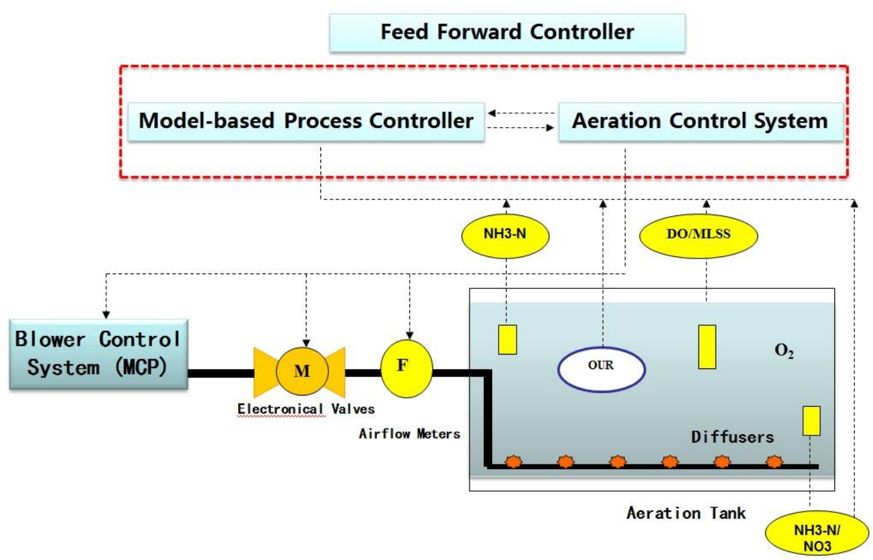

Figure 3. General Feed-forward Controller Diagram

<u>Model-based Process Controller</u>

The model-based process controller is designed to use a feed-forward control algorithm to calculate the proper DO set points for each control zone in the aerobic stages. By monitoring the influent flow rate and concentration and receiving an effluent target which operators can set anytime on the interface, this model-based system uses an optimization algorithm to determine the effect different DO set points will have on the effluent ammonia concentration and ensures the DO set-points system finally calculates are the lowest possible ones to maintain the effluent ammonia targets.

The fundamental on-site parameters for establishing the model are divided into two respects. Those data which is relating to the activated sludge is measured by the experimental equipment called “ABAM” which is used to detect the sludge Oxygen Uptake Rate (OUR), Nitrification Rate (NR), and Denitrification Rate (DNR). The composition of the influent loading is analyzed in the lab to determine some ratio values for the model, such as BOD/COD, TKN/COD, and NH4/TKN.

Figure 4. ABAM

Aeration Control System

The aeration control system is designed to perform DO tracking and maintaining. The control algorithm of the aeration control system at Bailonggang WWTP usesis based on a control cycle which operators set on the interface based on the stability of the influent loading. When a new cycle starts, the control system first calculates an airflow set-point for each DO control zone and then combines them into a total airflow set-point. This setpoint is communicated to the blower system, asking the blowers to adjust in order to satisfy the total airflow needs. After waiting some time for the blower to adjust to the total airflow set-point, the aeration control system starts to move all the valves to track their airflow set-points using a “Flow Coefficient (CV) to valve position” technique to calculate valve position. This makes the actual airflow get near to the airflow set-point in one movement. It then controls the valve to tweak open and closed until the airflow set-point is reached. This aeration control system also includes “Most Open Valve” control, which keeps the blower load down and efficiency high by focusing on keeping system pressure low. This is accomplished by ensuring that at least one of the 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.

Summary of Measured Values

In order to conduct the full Feed-forward process control system described above, the following signals were required to be received in the system.

Name	Number	Description
Airflow Meter	34	Two of them are installed at the main pipe to measure the total airflow rate and the rest are installed at each control zone air pipe.
Air Valve	32	Each control zone air pipe has one air valve
Turbo Blower	6	Airflow Control based, inlet/outlet vane controllable by its own Master Control Panel Maximum Airflow Rate for one blower: 75,000m^3/H Adjustable airflow range: 45%-100%
Dissolved Oxygen Meter	32	Each pass among the eight trains has one DO meter installed
MLSS Meter	8	Each train has one MLSS meter installed in the Anoxic zone
NH4 On-line Analyzer	1	Installed at the end of Anoxic zone
NH4/NO3 On-line Analyzer	1	Installed at the end of Aerobic zone
Temperature Sensor	4	Each tank has one temperature sensor installed at the Anoxic zone
Influent flow rate meter	4	Each tank pair has one influent flow rate meter installed before entering into the anaerobic zone

Figure 5: Numbers and Descriptions of Main Equipment Monitored and Controlled by Aeration Control System

Controlled Values:

For the final control target, the residual ammonia concentration at the end of aeration is used as a control set-point for all trains. This effluent ammonia concentration target set-point is selected by operators. The ammonia set-point can be changed on the user interface at any time.

Manipulated Values:

The DO set points for the individual aerobic stages are used to control the bioreactor effluent ammonia concentration. The controller DO set-point calculations are limited to a DO set point range and maximum step change selected by the operator.

Feed Forward Controller Hardware and Program

One touch screen industrial computer is used for the installation of the model-based controller program due the heavy calculation load. The interface was built using Visual Basic by Microsoft.

The operational modes and set points can be accessed, implemented, and modified directly through the user interface. Also in the computer, a data logging function was enabled using a SQL data service.

Additionally, soft-coded tuning parameters can easily be accessed through the Human Machine Interface (HMI), which allows for on-the-fly control tuning, giving plant operators and engineers the ability to adjust the system as necessary.

The process control engine is where the process model and optimization algorithm calculations are implemented. The mathematical software MatLab was used to implement the process control engine.

Results

To demonstrate the benefits of the advanced aeration control system, the performance of the control system was compared to manual operation of the aeration system. Figure 6 shows the measured DO over a one week period from one zone when the system was under manual aeration control. Figure 7 shows the measured DO and DO set-point for this same zone over a one week period when the system was controlled by the advanced aeration control system. Under manual control, the DO varies in response to influent loading changes. The DO ranged by as much as 3.9 mg/L, oscillating between values as low as 0.8 mg/L and as high as 4.7 mg/L over the week long sample period presented. When controlled by the advanced aeration control system, the DO was within ±0.3 mg/L of the set-point 93.07% of the time, and within ±0.5 mg/L of the set-point 99.09% of the time.

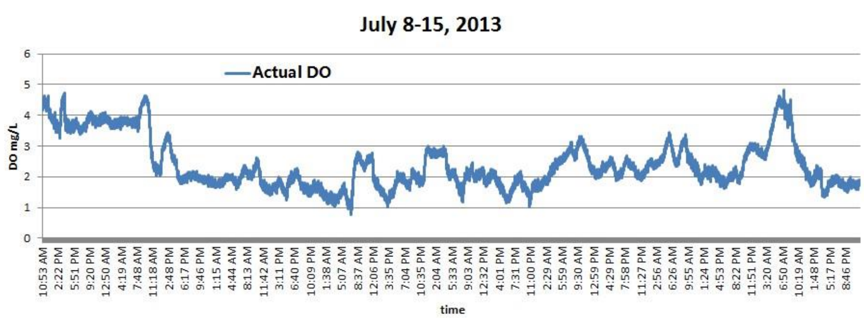

Figure 6: Actual DO Reading under Manual Control over One Week

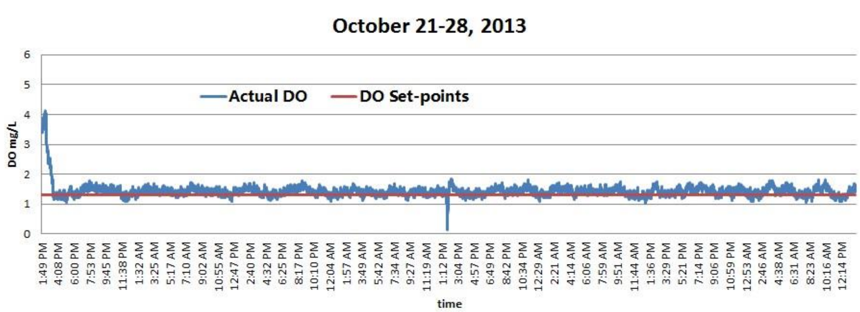

Figure 7: Actual DO Reading under Automatic Control over One Week

The difference of blower electricity consumption between manual control and control by the advanced aeration control system was also tested. To account for differences in the influent flow rate between the two controlled periods, the measured energy consumption of the aeration blowers was normalized per 10,000 metric tons of influent flow.

Two months of influent data, shown in Figure 8, from when the plant was under manual control was used to calculate a baseline energy consumption. The average energy consumption to treat 10,000 metric tons of influent flow was calculated as 1038.59 kWh while the average influent ammonia was 30.72mg/L.

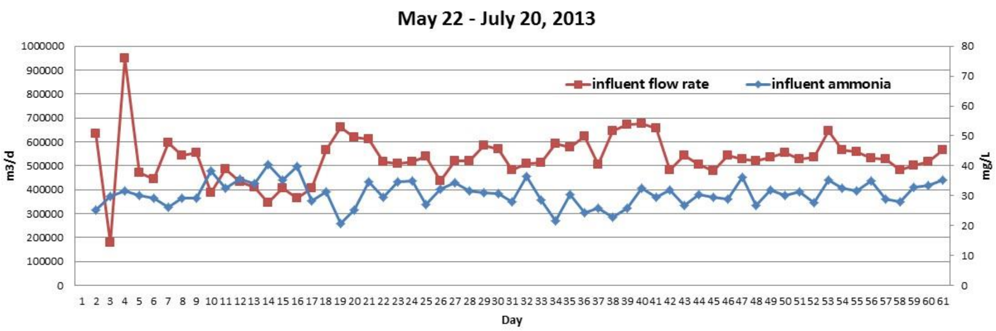

Figure 8: Energy Consumption baseline for manual control of two months of 2013

Two different time ranges were compared with the manual control basin line. These periods are shown in Figures 9 and 10. The average energy consumptions to treat 10,000 metric tons of influent flow was 835.09 kWh and 827.29 kWh for the two time periods, while the average influent ammonia was 36.99mg/L and 28.89mg/L.

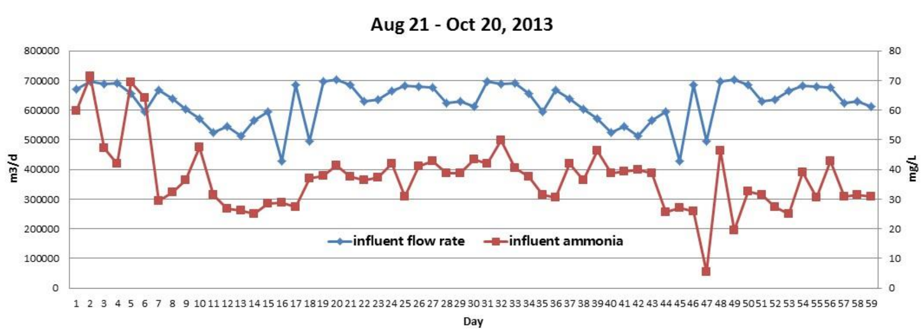

Figure 9: Energy Consumption for system control of two months of 2013

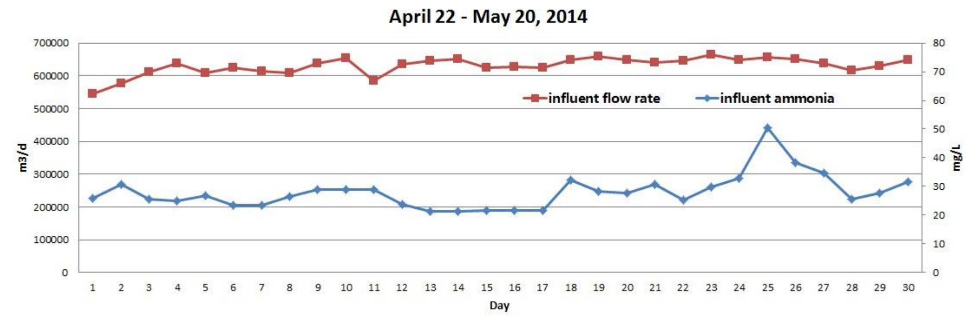

Figure 10: Energy Consumption for system control of one month of 2014

This represents an average savings of 19.9% compared to manual control. Assuming a 0.962 CNY per kilowatt-hour electricity price for summer (from June to September) and a 0.657 CNY per kilowatt-hour electricity price for the rest of the year, the advanced aeration control system is expected to save an average of 267,499 CNY ($42,460) per month.

Discussions

In order to implement and run a Feed-forward process control system in a plant with such a large scale, unique control solutions had to be developed to overcome issues which do not normally occur at smaller scale WWTPs.

First, the blower control was more difficult than typically encountered. The blower system manufacturer has its own deadband calculation method which is was based upon the total number of blowers. The blower system has 6 blowers with four of them expected to be operating and the other two are for back-up. Therefore, the deadband of the entire blower system was calculated using the sum of four blowers' maximum airflow rates, which resulted in a deadband of 4800m^3/H (the Phase 2 total airflow rate is typically between around 80,000m^3/H – 110,000m^3/H). Figure 11 shows the tracking accuracy under this dead-band setting.

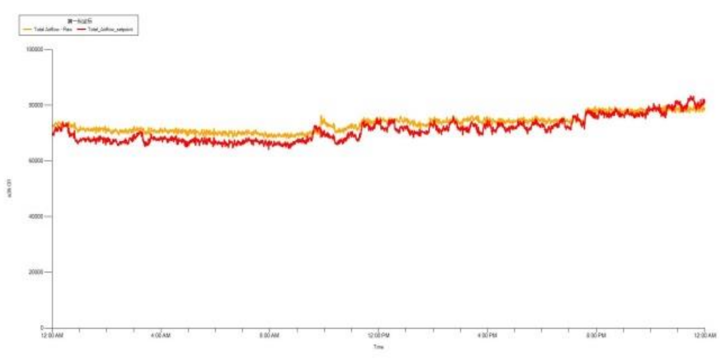

Figure 11: Blower Tracking Performance Under 4800m^3/H dead-band.

This deadband was based upon full loading conditions with all four blowers operating but under current conditions, this deadband was insufficient t. The loading hasn't yet reached its design capacity, so only two blowers running are typically running. With a 4800 m^3/H deadband, the airflow was too far from the setpoint to achieve good control. Additionally, having a large deadband let to increased pressure in the system if the airflow was higher than was required. Valves in the system would attempt to close due to the higher airflow, raising the pressure and decreasing efficiency Working with the blower manufacturer, the dead-band down and Figure 12 indicates we are having more accurate total airflow tracking performance and safety for the head pressure.

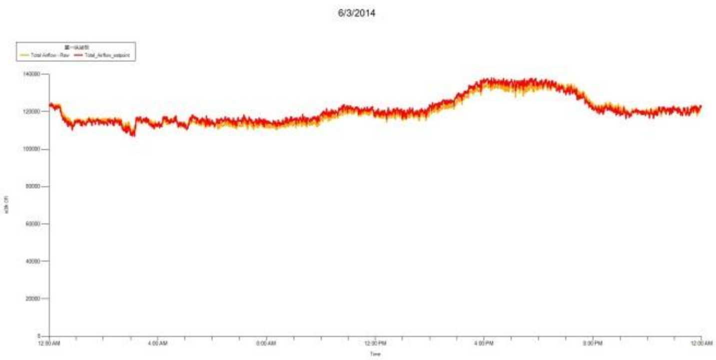

Figure 12: Blower Tracking Performance Under 2400m^3/H dead-band.

Secondly, each additional data collection device introduces an additional point of error or failure to a control system which relies on the health of that signal. To accommodate for the large number of airflow meters employed, and the subsequently increased risk of failure that follows, a sophisticated airflow multiplexing/redundancy algorithm was configured which allowed for signals generated by both individual zone airflow meters and total airflow meters to be reconciled despite individual unit miscalibration and unpredictable unit failures. The result is a smooth and robust feedback signal which the blower system can utilize despite occasional airflow meter malfunction.

Conclusions

Implementing an advanced aeration control system in Phase 2 of Bailonggang WWTP has not only improved DO control performance and stability with varying influent loading conditions, but it also has resulted in a substantial improvement in energy savings and a reduced cost of operations. Especially for a large WWTP such as Bailonggang, automatic control could bring tremendous benefits to it.