WE&T
water environment and technology

May 2015

Energy optimization

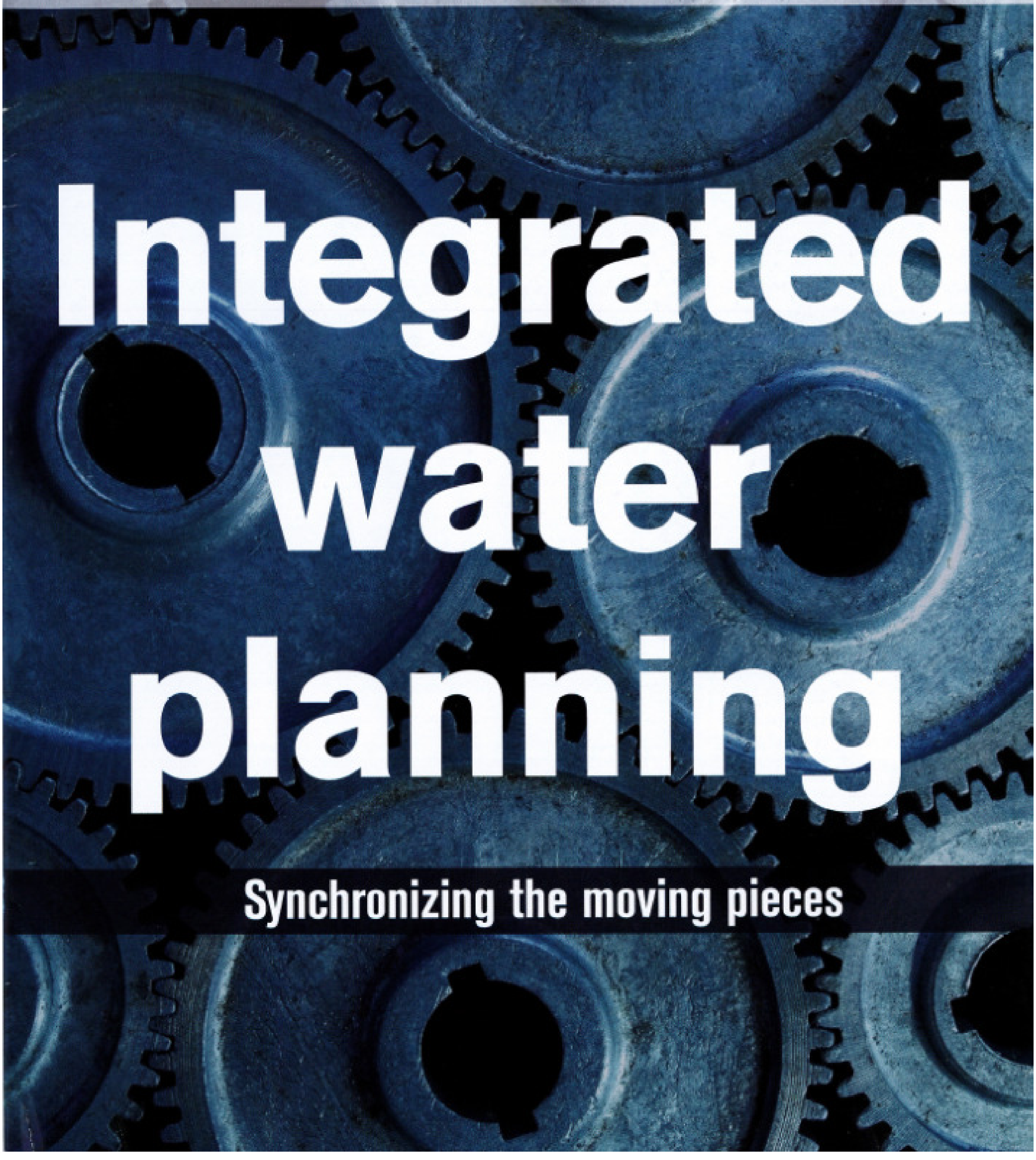
Workforce planning

Water reuse

Aeration

# Integrated water planning

## Synchronizing the moving pieces



# A need for air, with

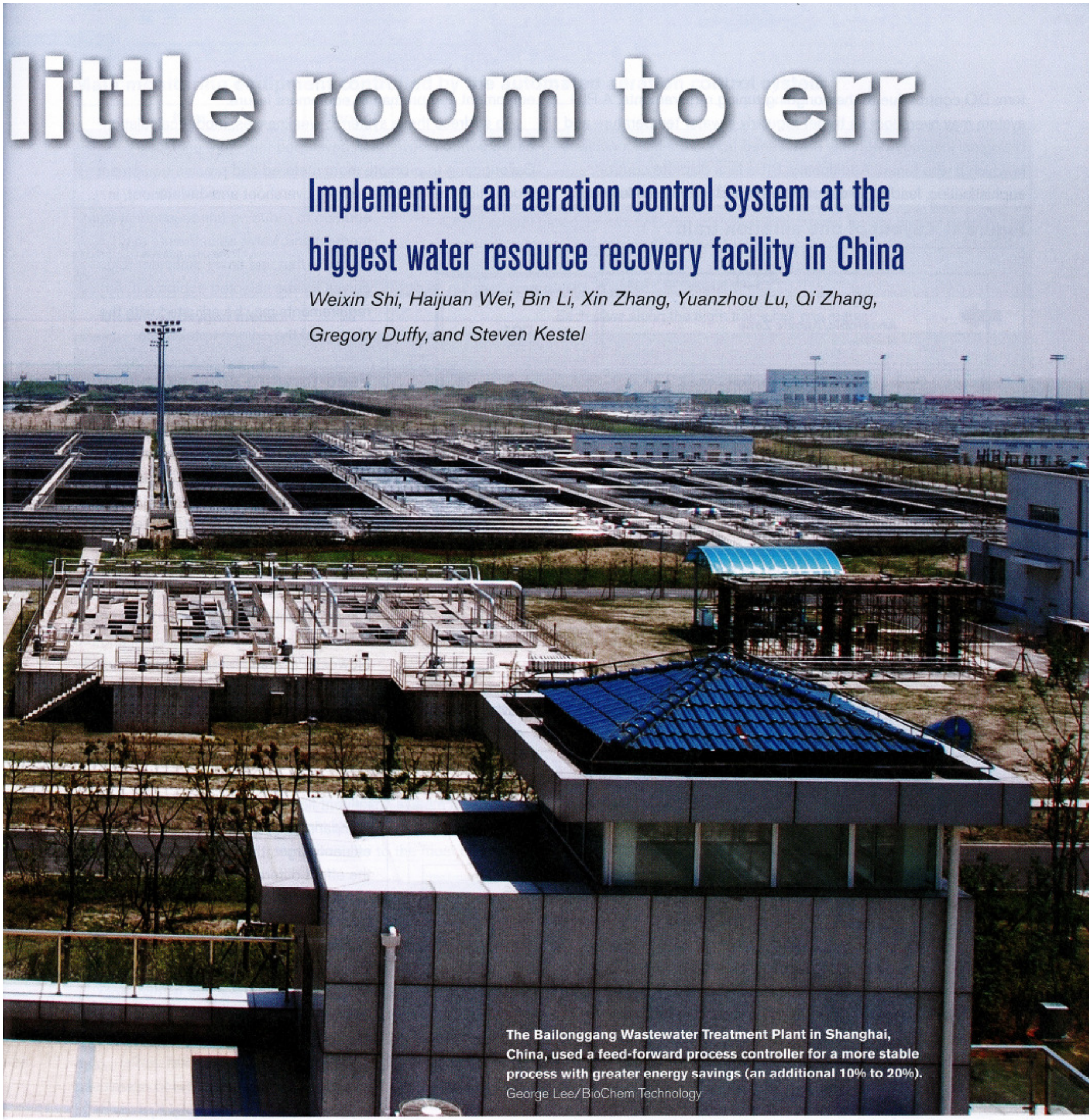
In recent years, China has begun to reap the benefits of installing and operating automatic process-control systems for wastewater treatment. The Bailonggang Wastewater Treatment Plant in Shanghai, China, is one of them. The facility serves an area of 272 $km^2$ (105 $mi^2$) and a population of 3.56 million. Total flow to the facility is expected to reach 3.60 million $m^3$/d (951 mgd) by 2020. Phase I, completed in 2008, expanded design capacity to 1.20 million $m^3$/d (528 mgd). Phase II was recently completed, with an additional operational capacity of 803 $m^3$/d (212 mgd) and a secondary treatment process consisting of eight identical trains in an anaerobic–anoxic–oxic (AAO) configuration (see Figure 1, p. 56).

To achieve the benefits of dynamic dissolved oxygen (DO) control, Bailonggang installed an advanced model-based aeration control system as part of its most recent expansion. Several issues arose during the system's implementation related to the large-scale application, but they were resolved, allowing the facility to reap the benefits of a more stable process with greater energy savings (an additional 10% to 20%) when compared to fixed DO systems.

# little room to err

## Implementing an aeration control system at the biggest water resource recovery facility in China

*Weixin Shi, Haijuan Wei, Bin Li, Xin Zhang, Yuanzhou Lu, Qi Zhang, Gregory Duffy, and Steven Kestel*



**The Bailonggang Wastewater Treatment Plant in Shanghai, China, used a feed-forward process controller for a more stable process with greater energy savings (an additional 10% to 20%).**
George Lee/BioChem Technology

### Dynamic versus fixed DO

Water resource recovery facilities do not typically run at design conditions throughout their lifetime; conditions often vary widely on a daily basis. While a typical baseline DO control system involves setting a fixed DO setpoint for each aeration-control zone, dynamic DO control systems adjust according to loading conditions and effluent goals for ammonia.

Residual DO in each aerobic stage of the process can be used to control the 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 nitrification results in a decrease in effluent ammonia, and the converse also is true: Lowering the DO concentration will increase effluent ammonia.

Dynamic DO control can be accomplished utilizing a feed-forward approach, a feed-back approach, or a combination. Feed-forward control requires on-line instruments, such as ammonia and nitrate analyzers, in the aeration tank to detect influent characteristics.

Proportional-integral-derivative (PID) control is by far the most prolific and least complex method to achieve a desired DO setpoint. However, PID systems often are unsuccessful for longterm DO control due to their ongoing tuning requirements. A PID system may overshoot its target regularly if water temperature and biological loading conditions have varied from the initial conditions in which it was tuned. Additionally, PIDs lack discrete control sophistication, leading to constant wear and tear on modulating equipment and premature equipment failure.

To address these systemic weaknesses, model/calculation-based controls have been developed that were used at Bailonggang to promote more metered and precise equipment modulation that prevent system overshoot and undershoot, in addition to reducing unnecessary system modulations. Valve adjustments may be made that use flow coefficient ($C_v$) curves for the selected equipment. Airflow requirements may be adjusted with the change of the oxygen uptake rate.

**Figure 1. Layout of one aeration train**

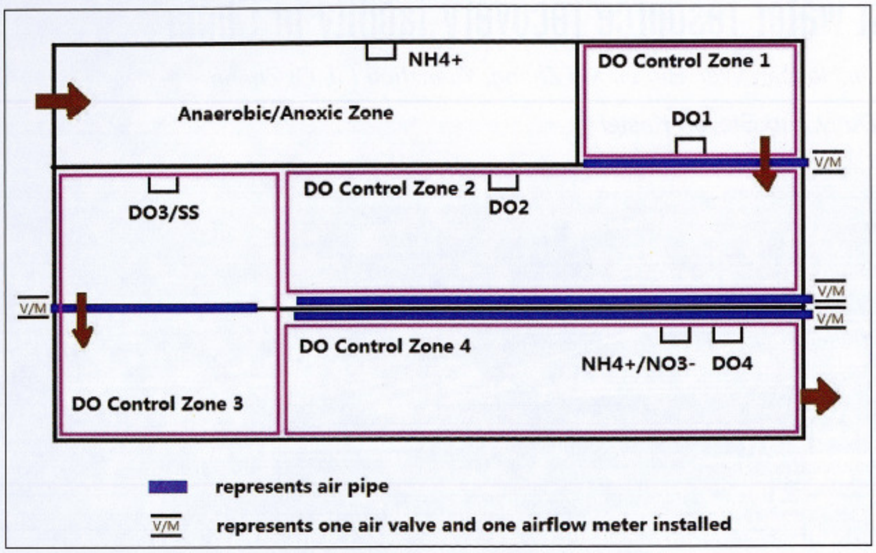



**Figure 2. Feed-forward controller process**

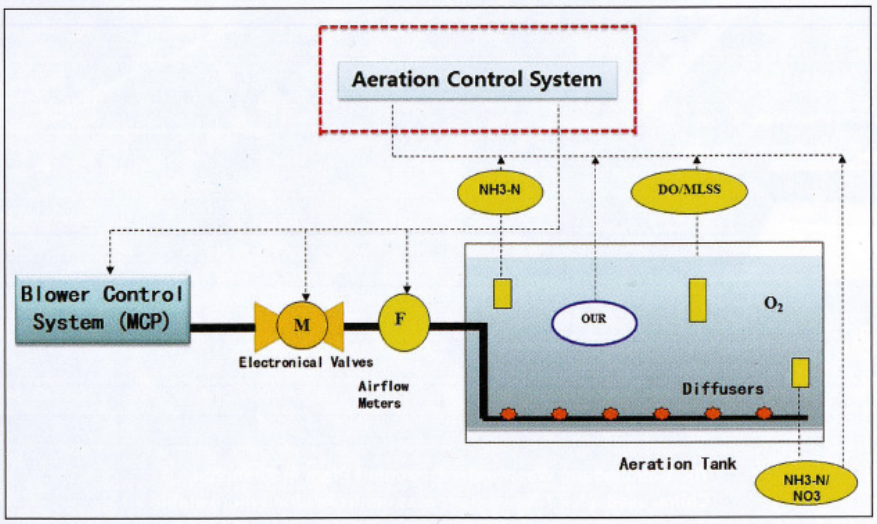
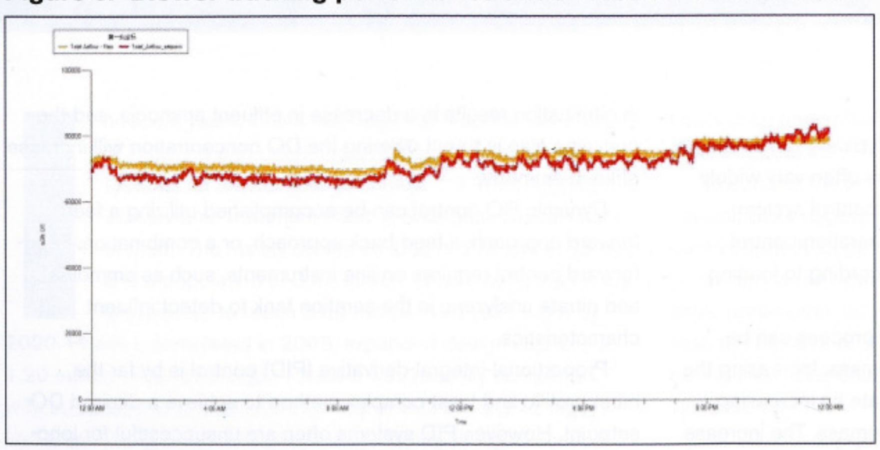



**Figure 3. Blower tracking performance under 4800 m³/H dead-band**



## Feed-forward process controller

The feed-forward process controller is a combination of two control systems: a model-based process controller and an aeration control system (see Figure 2, left). Both systems assist the facility in controlling biological nutrient removal (BNR) by adjusting sensitive system parameters such as internal recycle flow, return activated sludge, and waste stream flows, DO setpoints, individual zone airflow setpoints, valve position setpoints, and blower airflow setpoints.

***Model-based process controller.*** The model-based process controller uses a control algorithm to calculate the proper DO setpoint for each control zone in the aerobic stages. By monitoring the influent flow rate and concentrations and comparing it to an operator-programmed effluent target, the controller determines the effect different DO setpoints will have on the effluent ammonia and maintains the lowest possible DO setpoints.

Experimental equipment was used at Bailonggang to determine the activated sludge oxygen uptake rate, nitrification rate, and denitrification rate. Lab equipment was used to measure influent loads and determine ratio values for biochemical oxygen demand to chemical oxygen demand (COD), total Kjehldahl nitrogen (TKN) to COD, and ammonia to TKN.

***Aeration control system.*** The aeration control system tracks and maintains DO setpoints. The control algorithm for Bailonggang uses a timed control cycle that can be adjusted via a system interface. This timed cycle varies depending on tank depth, process size, and diffuser type. When a new cycle starts, the system first calculates an airflow setpoint for each DO control zone and then combines these setpoints into

## Main monitoring equipment controlled by the automated aeration control system

| Item | Amount | |
|---|---|---|
| **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.<br>Maximum airflow rate for one blower: 75,00 0m$^3$/H<br>Adjustable airflow range: 45%-100% |
| **Dissolved oxygen meter** | 32 | Each pass along the eight trains has one meter. |
| **Mixed liquor suspended solids (MLSS) meter** | 8 | Each train has one MLSS meter installed in the anoxic zone. |
| **$NH_4$ on-line analyzer** | 1 | Installed at the end of the anoxic zone. |
| **$NH_4/NO_3$ on-line analyzer** | 1 | Installed at the end of the aerobic zone. |
| **Temperature sensor** | 4 | Each tank has one temperature sensor installed in the anoxic zone. |
| **Influent flowrate meter** | 4 | Each tank pair has one influent flowrate meter at the influent end of the anaerobic zone. |

a single total airflow setpoint. This total airflow setpoint is then communicated to the blower system. After the blower adjusts to the total airflow setpoint, the aeration control system calculates valve positions using a "flow coefficient ($C_v$) to valve position" technique and begins adjusting the automated air control valves to attain zone-specific airflow setpoints.

This iterative metered adjustment allows valves to operate more efficiently, achieving the desired airflow with minimal valve actuations. The aeration control system's valve control logic also employs a "most open valve" methodology, which aims to reduce overall system pressure and subsequently lower blower load and energy consumption. At least one valve in the system is constantly held in a nearly completely open position, allowing the other valves to adjust and pull air away from or push air to the most open valve.

### Data gathered for process control

The full feed-forward process control system required the following data, which were collected with the equipment listed in the table (above).

***Controlled values.*** The residual ammonia concentration at the end of aeration is used as a control setpoint for all trains. This setpoint is selected by operators and can be changed on the user interface at any time.

***Manipulated values.*** The DO setpoints for each aerobic stage are manipulated to control the effluent ammonia concentration. The controller DO setpoint calculations are limited within a fixed range and by a maximum rate of change in the DO setpoint. The range and maximum rate of change are selected by the operator. These DO setpoints are achieved by manipulating blower airflow and automated control-valve setpoints to control airflow production and distribution, respectively.

***Hardware and programming.*** A touch-screen industrial computer is used for the model-based controller program because of the heavy calculation load. A front-end human–machine interface was developed using Microsoft Visual Basic so that operational modes, setpoints, and soft-coded tuning parameters could be accessed and modified directly and easily. The computer also contains a data logging and plotting module powered via a SQL-based database that runs concurrently with the control software.

The process-control engine, where the process model and optimization algorithm calculations are implemented, was developed utilizing MatLab and consists of a specially tuned set of equations based on the Activated Sludge Model No. 1 developed by the International Water Association (London).

### Numerous challenges encountered

Implementing a feed-forward process-control system at such a large-scale facility required unique control solutions.

**Figure 4. DO levels during manual-aeration control for 1 week**

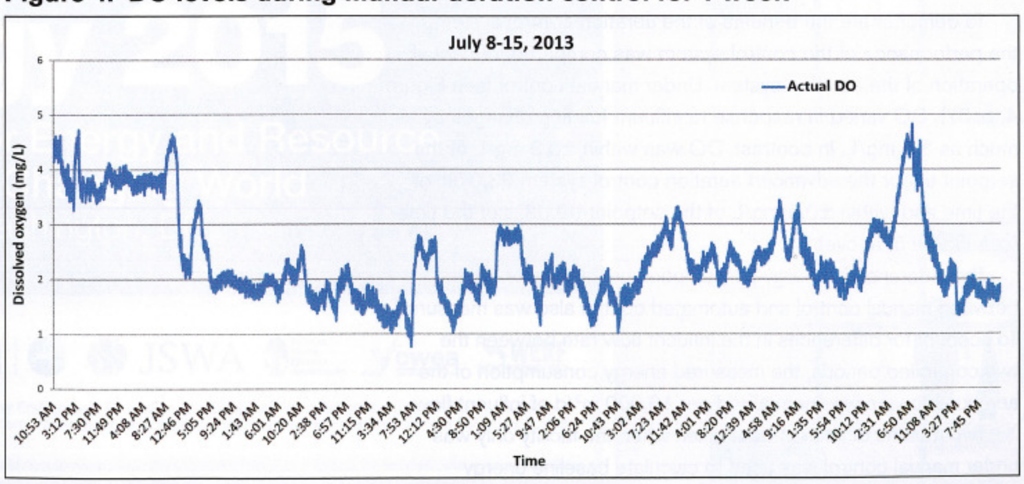
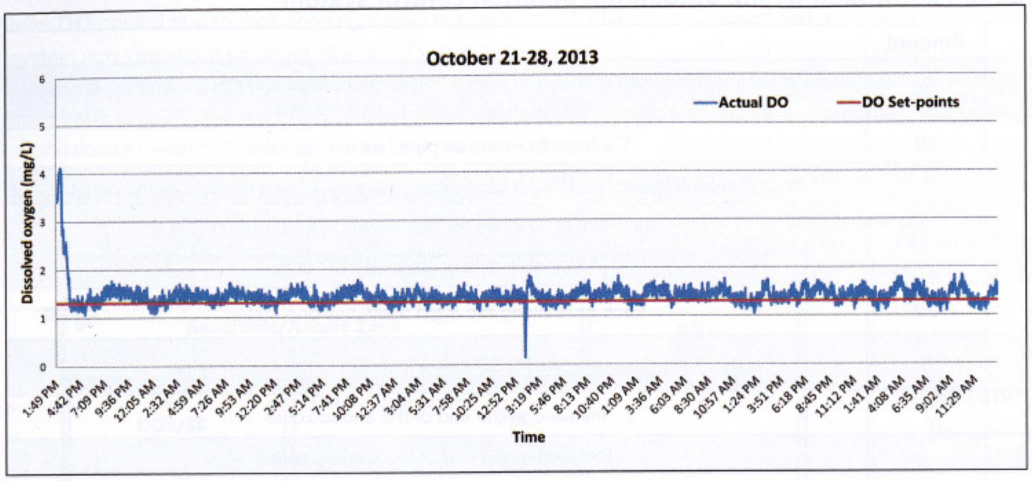


**Figure 5. DO levels during automatic-aeration control for 1 week**




consumption. The average energy consumption to treat 10,000 m³/d of influent flow at an influent ammonia concentration of 30.72 mg/L was 1038.59 kWh.

Two different time ranges were compared with the manual control baseline. The average energy consumption to treat 10,000 m³/d of influent flow were 835.09 kWh and 827.29 kWh for the two time periods, while the average influent ammonia was 36.99 mg/L and 28.89 mg/L. This represents an average savings of 19.9% compared to manual control. Assuming a 0.962 Chinese yuan (CN¥)/kWh cost of electricity for summer (June to September) and 0.657 CN¥/kWh for the rest of the year, the advanced aeration control system is expected to save an average of 267,499 CN¥ ($42,460) per month.

First, blower control was more difficult than typical. The manufactured blower system has its own built-in "dead-band," which prevents control actions when the blower output is within a certain range (or dead-band) of the setpoint. The range of the dead-band was based on the total number of blowers. The blower system has six blowers with four expected to be operating at any given time. (Two are for back-up.) Therefore, the dead-band was calculated using the sum of four blowers' maximum airflow rates, or 4800 m³/hr. The total airflow rate typically was between 80,000 m³/h and 110,000 m³/h based on the process demand. Figure 3 (p. 56) shows the tracking accuracy under this dead-band setting. This initial dead-band, however, was too large for optimal control, especially considering that the system was running only two of the four blowers. In an effort to compromise, a lower dead-band of 2400 m³/h was pushed into the blower controller, resulting in more accurate total airflow tracking performance.

A second problem encountered was the discovery that each device used to collect data introduced an additional point of error or failure to the overall control system. To accommodate for the large number of airflow meters, a sophisticated airflow multiplexing/redundancy algorithm was configured that allows discrepancies in signals to be reconciled. The result is a smooth and robust feedback signal that the blower system can utilize despite occasional airflow-meter malfunction.

## Better control, better bottom line

To demonstrate the benefits of the aeration-control system, the performance of the control system was compared to manual operation of the aeration system. Under manual control (see Figure 4, p. 57), DO varied in response to influent loading changes by as much as 3.9 mg/L. In contrast, DO was within ±0.3 mg/L of the setpoint under the advanced aeration control system 93.07% of the time and within ±0.5 mg/L of the setpoint 99.09% of the time (see Figure 5, above).

The difference in energy consumption by the blower system between manual control and automated control also was measured. 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 m³/d of influent flow.

Two months of influent data taken when the facility only was under manual control was used to calculate baseline energy

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