Case study

Xylem Smart Carbon Source Dosing System

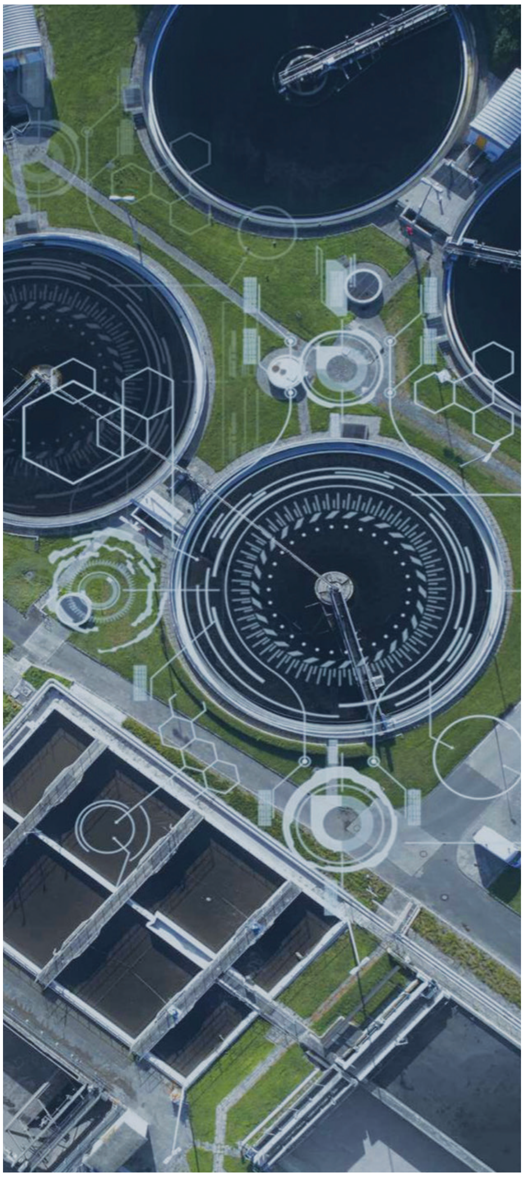
1. System Overview

1.1 Background

With the increase in industrial and agricultural activities, huge amount of wastewater containing nitrogen is produced. Biological nitrogen removal (BNR) processes have been widely adopted for treating nitrogen compounds to remove nitrogen from wastewater. To satisfy stringent effluent water quality criteria (Total Nitrogen and Ammonia), a supplemental external carbon source is often required when organic material in the wastewater has been oxidized in BNR processes.

However, delivering the proper external carbon feed dose is a delicate effort. Under-dosing can result in missing limit regulations. Over-dosing can lead to over-treatment for nitrogen removal, which results in the significant waste of external carbon source and the potential risk of COD over limit.

The above challenge has been puzzling the wastewater treatment plant managers. How to find an optimized solution to scientifically feed external carbon sources? When and how much volume can be added to BNR process to save total amount of carbon source while keeping the total nitrogen discharge limit is met?



1.2 Function Description

The digital intelligent external carbon source dosing system (hereinafter referred to as the intelligent dosing system) is a digitally integrated decision optimization system designed to effectively reduce the amount of external carbon source addition in the BNR process while meeting the required total nitrogen limit in the effluent through automated data acquisition, dynamic mechanism modeling and control optimization algorithm.
A typical schematic diagram is shown as below:

WTW
a xylem brand

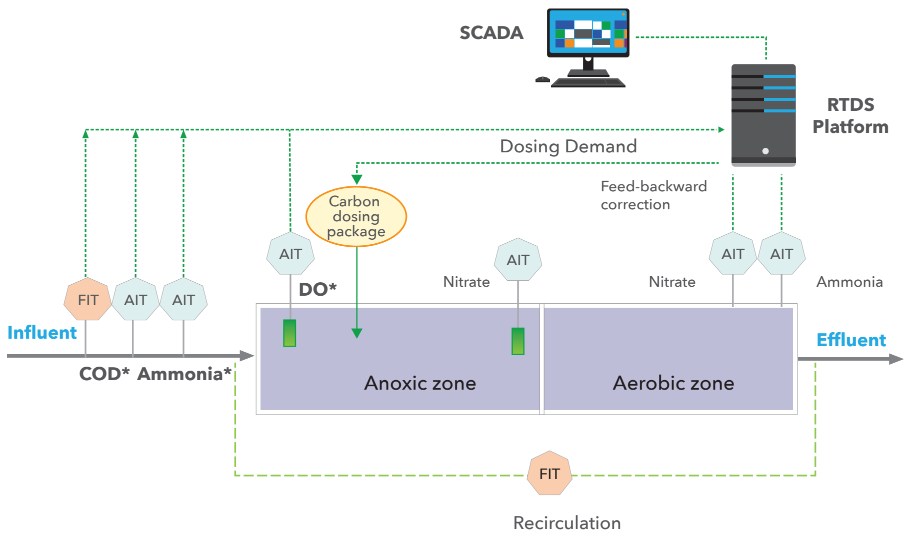


Figure 1. Carbon Source Dosing Schematic Diagram

The system has self-adaptation and self-learning functions to calibrate embedded mechanism model according to the actual process conditions. In the meantime, it can provide necessary early warning and reminder function to ensure whole system is operated in the most efficient manner and work as the function of "on-demand dosing "so that both stable operation and external carbon source reduction can be achieved.

1.3 Product Offering

The intelligent dosing system is composed of field instruments, real time decision support (RTDS) platform and carbon source dosing package (optional). A typical scope of supply is shown as below:

Figure 2. Typical Scope of Supply

3.1 Analytics Instruments

The supporting instruments of the intelligent dosing system are as followings:

Nitrate probe: Two nitrate probes in anoxic tank and aerobic tank respectively

Do probe: One Do probe in anoxic tank(optional)

COD probe: One COD probe in the inlet of the anoxic tank(optional)

Ammonia probe(analyzer): One ammonia probe or analyzer in aerobic tank (optional)

1.3.2 RTDS Platform

The RTDS platform is composed of a computer server along with related software, installed in the central control room of the treatment water plant. As the core component of intelligent dosing system, RTDS platform includes four subsystems: data processing module, intelligent decision module, dashboard module and alarming module. The control principle is illustrated in following:

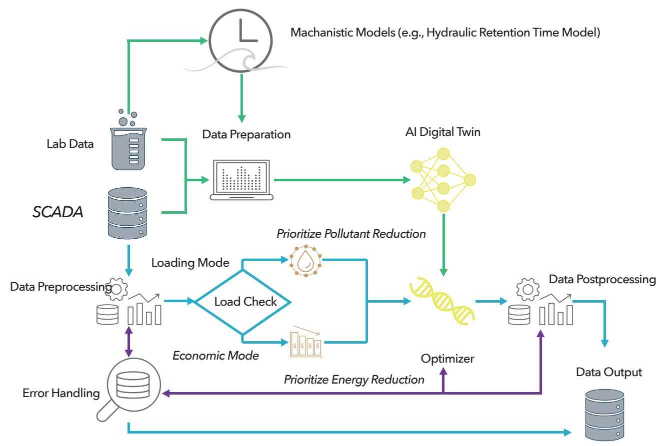


Figure 3. RTDS Platform Control Principle

1.3.2.1 Data Processing

The data processing module serves as a communication hub between RTDS platform and other field devices. On the one hand, it is used to receive relevant equipment and process information from field instruments, and to store, filter, clean and structure the data. After the system acquires real-time data, it can make appropriate corrections to missing values, outliers, etc., And perform transformations to adapt to the algorithm. On the other hand, it transmits the control signals (target dosage, start-stop command, etc) from control optimization module to external carbon dosing pumps.

1.3.2.2 Intelligent Decision

Intelligent decision module is composed of three subsystems:

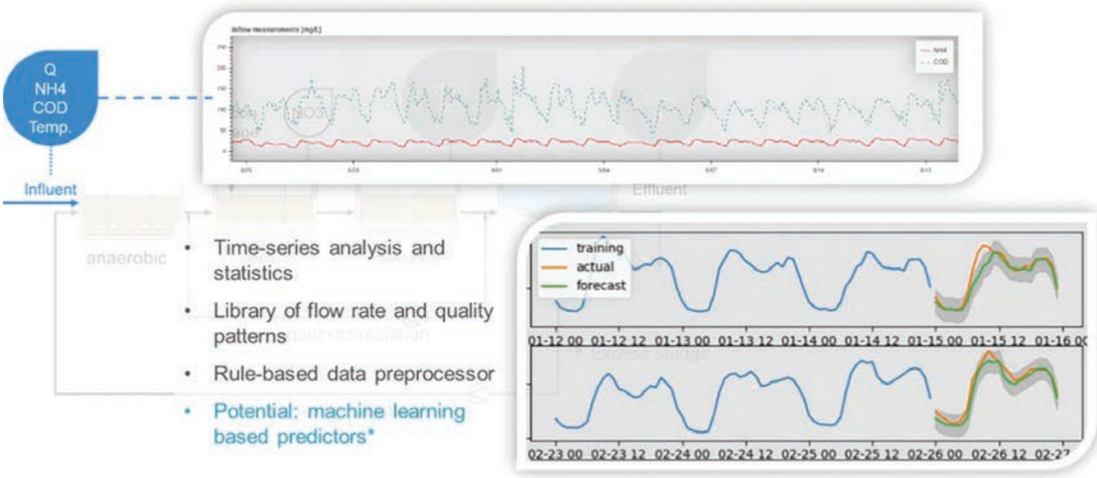


Figure 4. Influent Water Prediction Principle

1). Influent Water Prediction

The influent water prediction utilizes real-time data and historical data. Firstly, it identifies and processes abnormal data in real-time influent water flow rate and quality data through operational experience. Secondly, an empirical daily water quality trend pattern library is established to provide a benchmark for water flow and quality prediction through pattern recognition of historical data. Furthermore, a water flow and quality prediction model is established through statistical prediction methods and deep learning methods to provide data foundation for parameter calibration of subsequent mechanism models.

The logic principle is illustrated in following:

2). Dynamic Mechanism Modeling

The dynamic mechanism model is based on the ASM2d model of the International Water Association, coupled with parameters such as influent water quality and process indicators. It takes account for following contents:

- Biological nitrification and denitrification
- Hydraulic retention time
- Back-flow, aeration and carbon source dosing

$$\begin{pmatrix} TN_{out} \\ NH4_{out} \end{pmatrix}(t) = f \begin{pmatrix} Q_{in} & N03_{aero} & R \\ NH4_{in} & DO_{aero} & r \\ COD_{in} & NH4_{aero} & C \end{pmatrix}$$

The model is continuously calibrated through historical and real-time data to find the control parameters that have the most significant impact on the effluent water quality, and the correlation between carbon source dosage and nitrogen removal efficiency, and finally, to identify the highest efficiency range of external carbon source dosing under given working conditions.

3). Real Time Control Optimization

The real time control optimization can automatically identify the treatment load at present and in the future based on the output from influent water prediction model. If it is identified as a high load, it will give priority to ensuring that the effluent reaches the regulation limit; if it is identified as a low load, the optimization goal will be adjusted to stabilize the effluent and save external carbon sources.

After the optimization goal is given, the model will combine the results of sensitivity analysis to give the optimal target rate of external carbon source dosage. As a preventive protection measure, the algorithm can automatically limit the switch frequency and range of the dosing target value within an acceptable level to avoid frequent start-stop of dosing pumps.

The data flow of control optimization is illustrated as following:

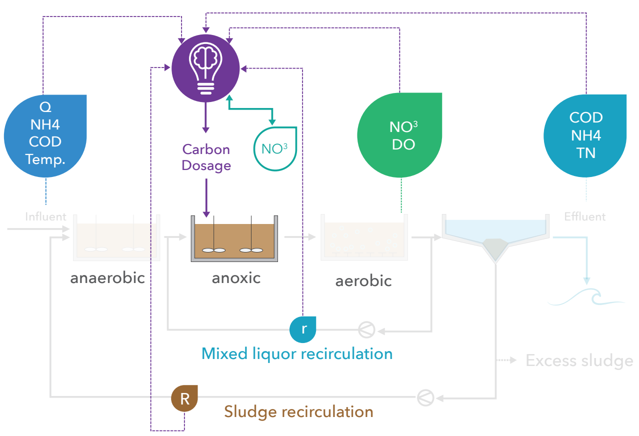


Figure 5. Data Flow of Control Optimization

1.3.2.3 Dashboard

The dashboard integrates and manages the operation data of each module, generates various thematic map applications, and forms a full-process comprehensive display of the daily operation of intelligent dosing system. It can be integrated into the large screen of the central control room of the sewage treatment plant to provide real-time analysis of operational index.

1.3.2.4 Alarming

When abnormalities occur in instruments and equipment that have an impact on model calculations, the RTDS platform can provide hierarchical alarms for abnormal events and adopt different strategies in response to the given alarm levels.

1). Alarm Types:
Alarms are defined into three types.

- Real-time alarm information of equipment:
- Overrun data value alarm:
- Rapidly changing trend alarm:

2). System on-line evaluation and prediction and early warning

According to the various monitoring and sensing points of the system, the collected monitoring data can be updated in real time as the calculation boundary conditions of the on-line model, such as the influent flow data of the anoxic tank, nitrate in the effluent, etc. These data are brought into the process model as boundary conditions, based on which the model can perform real-time calculations and on-line evaluation of the current operating status of the system, such as: organic load, changes in internal reflux ratio, changes in sludge concentration, etc.

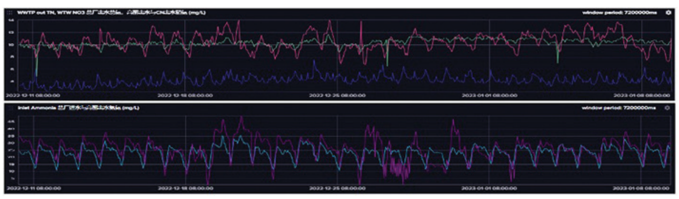


Figure 6. Online evaluation and early warning

1.3.3 Carbon Source Dosing Package (optional)

The carbon source dosing package is composed of storage tank, dosing pump, instruments, valve, PLC control system and etc.

The RTDS platform communicates with the carbon source dosing local control cabinet through Ethernet. The dosing package shall include an independent PLC control system. After receiving the dosing volume signal sent by the dosing PLC control system, the carbon source dosage of the dosing pump is adjusted by frequency conversion. Also, the dosing volume signal is fed back to the intelligent dosing system.

The dosing amount provided by the dosing package will fluctuate at any time with the water inflow and water quality of the system. The dosing control system can timely respond to the dosing amount required by the anoxic tank, also the actual dosage shall be stable. When the change value of dosing quantity output by PLC program is within 2% to 3% and the response time is not more than 5s, the flow of dosing pump does not change.

The technical requirements of the dosing package are as follows:

- The carbon source storage tank shall be considered for 7 to 14 days, and the design should consider cofferdam, anti-corrosion and thermal insulation.
- The flow of the metering pump shall be able to be adjusted in the range of 0% to100% in both manual and automatic modes, with an accuracy of ± 1%. The level transmitter shall be able to output 4 to 20mA continuous signals, and the automatic pump stop function shall be available when the level of storage tank is low in order to prevent damage.
- The dosing package shall be equipped with a frequency conversion control cabinet and can automatically adjust the dosage. At the same time,the control system should have alarm and protection functions.
- At the same time, it shall be able to indicate the status of the metering pump, instrument and agitator (if have). It should equipped with alarm indication of dosing pump failure, low liquid level of solution tank and etc., As well as provide corresponding 4 to 20mA signal to the control system.
- The inlet line shall be equipped with a flushing valve for the automatic flushing in case of long-term shutdown of the package or pipe blockage. It is recommended to use clean water for flushing.

Figure 7. Carbon source dosing package

2 Case Studies

Case One:

Background: A domestic sewage treatment plant located in North of China with the capacity of 150,000 m³/day. The total nitrogen (TN) discharge is required to be under 10 mg/L in compliance with local regulation.

Outcome: At the end of April 2023, optimization results from this first phase were compared against the previous month data and data from parallel line.

Followings are figures to illustrate external carbon source saving from three different comparison dimensions, where line A2 is with the proposed solution as treatment group and in line A1 is without the solution as control group.

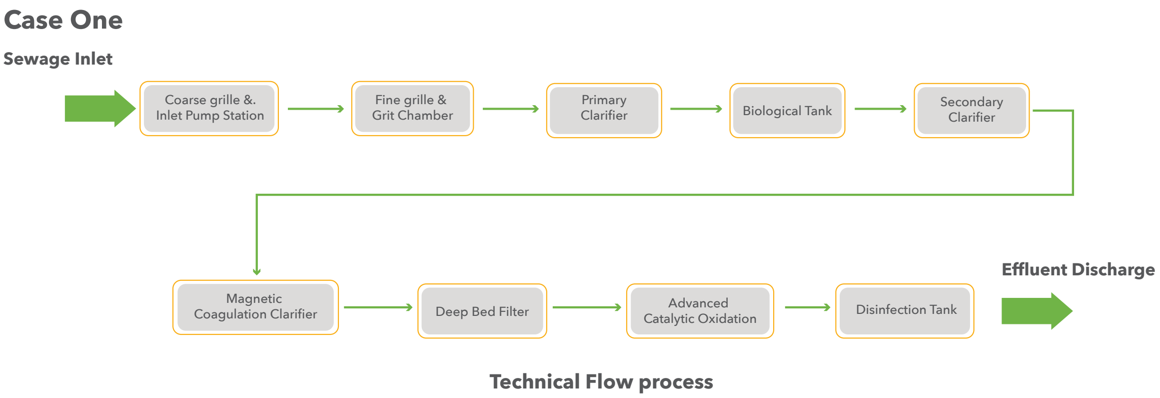


Figure 8: The technical flow process of Case one

Challenge: Since influent C/N ratios is relatively low, the plant has to inject large amounts of external carbon source to meet TN discharge requirement. The annual cost of external carbon source is up to $1.8 Million.

Solution: In the beginning of 2023, the client partnered with Xylem to apply the intelligent dosing system. The objective was to better understand, control and increase the efficiency of external carbon source addition with following targets:

1. Discharge of Effluent Nitrate < 6 mg/L
2. Fluctuation of Effluent Nitrate is within ±1.0mg/L
3. External Carbon Dose Consumption Saving >10%
4. Maintenance cycle of analyzer > 1 month

With above target, Xylem's intelligent dosing system solution provided followings:

- 3 sets of WTW spectrum nitrate analyzer
- 1 set of RTDS platform

In April of 2023, after several months commissioning, RTDS platform was activated to predict and calculate the best set points to operate the external carbon source addition for one of two parallel biological treatment lines, leaving the other one as existing control scheme as comparison.

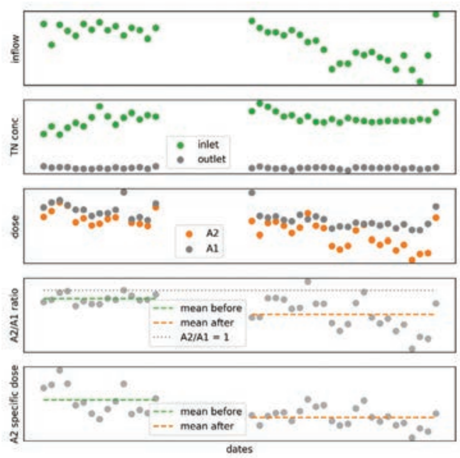


Figure 9. Dosing efficiency comparison in month of April 2023 (daily average)

From top to bottom:

- Inflow: influent flow-rate of WWTP;
- TN conc: TN concentration in WWTP influent and effluent;
- Dose: Carbon source dosing flow-rate. It has shown that carbon dosage in A2 is more actively adjusted than dosage in A1 in response to variations of inlet flow and inlet TN concentration.
- A2/A1 ratio: Ratio of carbon source usage between A2 and A1. After implementing the solution, the mean value of the ratio is reduced by 26.86%.
- A2 specific dose: Carbon source dosage per unit TN removal in A2. After implementing the solution, the mean value of the specific dosage is decreased by 28.04%.

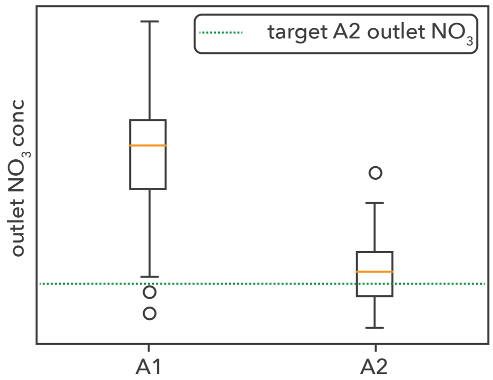


Figure 10. Stability comparison of effluent nitrate concentration between A1 and A2

The two box-plots are generated with hourly effluent nitrate concentration measurements for A1 and A2 within the same three-day-long duration.

The mean nitrate concentration in A2 is 12.61% smaller than in A1, while the standard deviation in A2 is 51.99% smaller than in A1. The difference between the mean nitrate concentration in A2 and its target value is within 35.88% of the standard deviation of the nitrate concentration in A2.

Since implementing Xylem's intelligent dosing system, the WWTP has shown more than 25% reduction in external carbon source usage, corresponding to $400,000 saving annually. In addition, the effluent TN discharge concentrations continues to maintain regulatory compliance.

Case Two:

Background information: A domestic sewage treatment plant located in Northeast of China with the capacity of 80,000 m^3/day and a total carbon source cost of 8 million yuan/year.

The process and carbon source dosing system scheme of the sewage treatment plant is shown in the following figure:

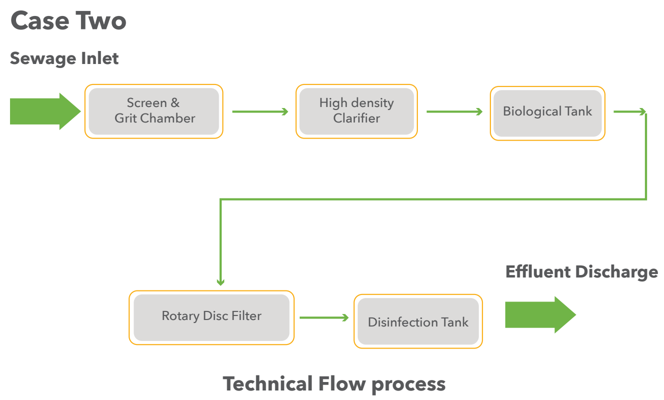


Figure 11: The technical flow process of Case Two

Scope of Supply:

2 sets of WTW spectrum nitrate analyzers
1 set of WTW DO analyzer
1 set of RTDS platform

Operation results:

- Fluctuation range of outlet nitrate: target value ± 0.5mg/L
- Technical expertise of instrument operation and maintenance personnel: none
- Operation and maintenance period of spectral nitrate instrument: 6 to12 months
- Operation and maintenance period of dissolved oxygen instrument: 1 to 2 months
- Operation and maintenance duration: 5 to10 minutes/time/set
- Increase of outlet stability: 50%
- Carbon source savings: 15%+