Research on Intelligent Control System of A/A/O Process for Wastewater Treatment Pilot Based on ASM2D and Fuzzy Model

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Abstract. The paper focuses on the design and implementation of intelligent control system for actual wastewater treatment. The objective of this project is to develop an intelligent optimization control system for biological process based on on-line sensing parameters. The control logic of system based on the simplified ASM2d model and fuzzy logic. The system integrates data input and output modules, simulates the biological reaction, and optimizes the control parameters of biological treatment process, such as controlling aeration, dosing and internal reflux ratio. Real-time intelligent optimization control system optimizes the operation effect of wastewater treatment, ensures the water quality to reach the standard and achieves the goal of energy saving and consumption reduction.

1. Introduction
At present, China's wastewater treatment automatic control system is backward, wastewater treatment operation costs remain high. It greatly hinders the development of wastewater treatment in small and medium-sized cities. How to establish an effective intelligent control system and optimize operation to reduce operating costs, which is of great significance.

Differences in weekday and weekend living habits as well as winter, summer, rainy season, dry season alternating cause water quality and quantity of the changing wastewater treatment plant, a wastewater treatment plant is difficult to reach a steady state. However, at present, the operation control of most wastewater plants is fixed dissolved oxygen and internal reflux ratio, or adjusted according to the experience for water quality of inlet. The actual operation is inconsistent with the actual situation of the influent of the WWTP or the operation is lagging, which will cause the outlet of WWTP cannot meet discharge standards under the peak load of the incoming wastewater. Therefore, it is necessary to research and promote intelligent control systems to improve the level of urban wastewater treatment technology.

Intelligent control is an advanced stage of the development of control theory. Its main goal is to enhance the robustness of the system through the learning and adaptation of the control system. The complex control system adapts to new requirements by continuously learning according to the environment in which the system is located, changes in operating conditions, and changes in control objectives. There are many successful applications in wastewater treatment in countries such as Europe, the United States, and Japan[1-6]. At present, the more successful intelligent control systems mainly have the following three types: fuzzy control[7-9], neural network control[7-9], and expert control system[6, 14].
Fuzzy control realizes the control by simulating human's logical reasoning ability and using human experience and knowledge. Due to the model is non-parametric, the calculation is small, the real-time performance is good, and it has certain robustness. But it does not have self-learning ability[9, 15, 16]. The neural network is mainly to simulate the mapping ability of human brain neurons. It can learn the existing operational data and establish a non-parametric model of the system to realize the nonlinear mapping of the system[2, 10-13, 15, 17]. It can predict the operation of the system to improve the effectiveness of the sewage treatment system. The neural network-based control system has strong learning ability, but it cannot apply the previous non-quantitative experience knowledge. Expert system has the strongest dependence on existing experience and weak learning ability. It is not applicable when the experience of water treatment intelligent control experts is not rich enough and the expert experience cannot be unified.

Through the above analysis, it can be seen that there are still some defects in many types of intelligent control technologies. Therefore, it is necessary to take the actual WWTP as the research object and apply the dynamic model to establish the wastewater treatment intelligent control system. In recent years, with the further improvement of the function and stability of online monitoring instruments, automatic control systems based on online monitoring, analysis and control have been promoted and applied. The application of various advanced model-based multivariable control techniques is also becoming more sophisticated. The South Bermuda Wastewater Treatment Plant in the United States transformed the original conditioning tank into a biochemical reaction tank, and then added a matching settling tank and filter tank. After applying the bioprocess intelligent optimization control system developed by Myratek, the discharge of the treated water was achieved. And can reduce part of the energy consumption. The practical application of the Enfield wastewater treatment plant in Connecticut, USA, shows that the intelligent process control system can increase nitrogen removal efficiency by 36% while reducing aeration by 19% [18, 19]. Qin Jianjun[20-22] and others have also started the research of intelligent process control system based on ASM model, taking BNR system as the object, using on-line water quality monitor to collect dynamic inflow data; by controlling the conversion signal, the on-line monitoring data are input into the computer to simulate, and the optimal working conditions under the corresponding water quality are obtained and fed back to auto-control equipment. The computer commands the equipment to run under the optimum parameters. Based on the on-line monitoring of water quality and quantity, mathematical simulation of optimal operating conditions and automatic control of process parameters, a four-tier distributed control system was established. The system can realize the digital automatic control of the process and achieve energy saving and consumption reduction on the premise of guaranteeing the water quality to meet the discharge standards. However, the scale of the system is small, and the control logic of the system is far from the actual use of the WWTP.

This paper is based on the project of "Research and Development of Key Technologies for Total Nitrogen Removal in WWTP Based on Nitrogen Balance", which is a key technical project of Shenzhen Science and Technology Innovation Creation Committee. The paper focuses on the design and implementation of intelligent control system for actual wastewater treatment. The objective of this project is to develop an intelligent optimization control system for biological process based on sensing parameters (ammonia nitrogen and nitric acid nitrogen). The system is based on the control logic algorithm of nitrogen balance principle and simplified ASM2d model. The system integrates data input and output modules, simulates the biological reaction, and optimizes the control parameters of biological treatment process, such as controlling aeration, dosing and internal reflux ratio. Real-time intelligent optimization control system optimizes the operation effect of wastewater treatment, ensures the water quality to reach the standard and achieves the goal of energy saving and consumption reduction.

2. Materials and Methods
This project is based on the operation of a 100 m³/d A/A/O pilot plant in the actual sewage plant to test the feasibility and reliability of the control system.

2.1. Basic situation of WWTP
The pilot test site of this project is located in a WWTP in Longhua, Shenzhen, with a design scale of 200,000 m$^3$/d. The actual daily water treatment capacity is about 220,000 tons. The main wastewater of this WWTP is the domestic and industrial wastewater produced by Guanlan Street. The effluent quality meets the 1A standard of "Pollutant Discharge Standard of Urban Sewage Treatment Plant". The improved A2/O activated sludge process was used in the wastewater treatment process. The monthly variation of water quality and quantity in 2017 is shown in Figure 1.

![Figure 1. The monthly variation of wastewater COD and flow of WWTP in 2017](image)

The average wastewater quality from August to October during commissioning is shown in the following table 1.

| Month | COD(mg/L) | BOD$_5$(mg/L) | pH  | SS(mg/L) | TN(mg/L) | NH$_4$(mg/L) | TP(mg/L) |
|-------|-----------|----------------|-----|----------|----------|--------------|----------|
| Aug.  | 147       | 46.2           | 7.34| 185      | 20.8     | 13.8         | 3.44     |
| Sep.  | 119       | 36.7           | 7.26| 92       | 23.9     | 16.9         | 2.67     |
| Oct.  | 143       | 42             | 7.25| 155      | 28.6     | 22.1         | 3.38     |
| Avg   | 136.3     | 41.6           | 7.3 | 144.0    | 24.4     | 17.6         | 3.2      |
2.2. Parameters of the pilot

The dimensions of each structure of the pilot are shown in Table 2 and the layout diagram is shown in Figure 3.

Table 2 The dimensions of each structure of the pilot

| Structure  | Size(m)       | Quantity | Material |
|------------|---------------|----------|----------|
| Anaerobic  | 1.6×1.5×3.0   | 1        | Steel    |
| Anoxic     | 1.6×1.5×3.0   | 1        | Steel    |
| Oxic       | 3.4×1.0×3.0   | 3        | Steel    |
| Clarifier  | 1.5×1.0×3.0   | 2        | Steel    |

Figure 3 The layout diagram of pilot

The instrumentations and equipment’s configuration of the pilot is shown in Figure 4. The influent and effluent are equipped with COD, TN/TP, NH4/NO3, pH, SS and flow meter, anaerobic tank monitoring pH/ORP, anoxic tank monitoring DO, pH/ORP, NH4/NO3, aerobic tank 1 monitoring DO, MLSS, aerobic tank 2 monitoring DO, aerobic tank 3 monitoring DO, pH/ORP, NH4/NO3. The internal recycling flow and external recycling flow are monitored by liquid flow meter. The air supply of the 3 aerobic tanks are monitored by flow meter, and an electric regulating valve is arranged on each branch pipe and the air main pipe to regulate the air flow. Other equipment includes Two Roots blowers, power 0.75kw/set, two inlet pumps 0.75kw/set, 3 sets of nitrifying liquid return pump, 1.1kw/set, 2 sludge return pumps, power 0.75kw/set, residual pollution One mud pump, 0.55kw, a peristaltic pump to add carbon source.
2.3. Control system design
The structural diagram of the pilot control system is shown in Figure 5.

2.3.1. Activated sludge process system
This subsystem includes three functions. They are equipment design and processing, pilot run start, and operation adjustment. We have to design and construct water processing pool, to install sensors, blower, pumps, valves and PLC units in order to realize this system.

2.3.2. Monitoring system
In this subsystem, we have to design the SCADA system to monitor the water quality and process operation parameters in real time, and get the process data such as monitoring water quality monitoring instrument and sensor, blower frequency, electromagnetic valve and electromagnetic switch, water pump, agitator and aeration device. Automatic control system includes PLC application design & field bus technology. Its purpose is to acquire shop floor data, control equipment’s operation component and provide communication channel between devices and monitoring software. The main task of the interface function is to input the collected data of on-line monitoring system into the mathematic model forecast system and feedback the simulation data of the real time optimal operation to the automatic control system in order to adjust the process parameters.
2.3.3. Intelligent control software system
This subsystem includes three functions. They are mathematic model forecast system, Operation execution system, and Process control logic system.

(1) Mathematic model forecast system
The main function of the mathematical model forecast system is to integrate the data input and output module of the monitoring system. According to the hydraulic conditions and biological response of bioreactor, the system optimizes the biological treatment process control parameters such as DO, sludge discharge, sludge recirculation and internal recirculation. The model is based on activated sludge model (ASM2d) and empirical formula. Via the Anaerobic-Anoxic-Oxic (A2O) process, the error analysis of the test data was carried out, the model was checked and validated, and the stoichiometric coefficients and kinetic parameters of the model were determined. The quality of dynamic influent water is used as the boundary condition for dynamic simulation analysis. The purpose is to make the effluent quality higher than the discharge standard, and optimize the parameters of biological treatment process.

(2) Operation process execution system
According to the process control criteria, PLC station is set to automatically control the reflux pump, fan, valves and other water treatment equipment. Those control parameters including the back flow, the motor rotational speed of frequency conversion fan and valve opening. Finally, we can achieve the required process return ratio and DO parameters of aeration pool.

(3) Process control logic system
In order to ensure the stability and stability of process control system, some process control logic should be developed to deal with some abnormal conditions. It includes the status monitoring and the effectiveness of the calculated process control parameters, and the validity of the instrument readings, and so on. For example, DO control range for general control anoxic pool is 0.05-0.5mg/L, and aerobic zone is 0.5-3.0 mg/L. If DO reading is over the range, it needs to alarm at this time. Also, it needs to analyse if the instrument reading is not correct, or fan and valve control is not in place.

3. Result and discussion

3.1. Fixed parameter operation results
The pilot in August 2018 is the operating period of fixed operating parameters, the influent flow rate is 100m^3/d, the nitrification liquid reflux ratio is 100%, the sludge external reflux is 75%, and the DO of the three Oxic tanks is controlled to be 2.0, 1.5, 1.0 mg/L by adjusting the electric valve. In the period of fixed operating parameters, the total air flow is fixed as 36m^3/h. The sludge is discharged 2 m^3 every day. The TN in the effluent is shown in Figure 6, and the effluent compliance rate is 57.5%.

3.2. Dynamic parameter operation results
The pilot plant was operated in September 2018 with the dynamic operating parameter. The influent flow rate was 100m^3/d. The nitrification liquid reflux ratio was adjusted according to the nitrate concentration at the end of the aerobic tank and the nitrate concentration in the anoxic tank. The adjustment range was 50-300. %, the external sludge is refluxed 75%, and the DO of the three aerobic tanks is dynamically set according to the COD of the inlet and the ammonia nitrogen concentration of the anoxic tank. The specific algorithm is in accordance with the simplified ASM2D model and fuzzy logic to meet the needs of microorganisms and aerobics environment, the adjustment range is 0.5-3mg/L, and the sludge is discharged 2 m^3 every day. The TN in the effluent is shown in Figure 6, and the effluent compliance rate is 100%.
3.3 Energy consumption analysis

Since the pilot is relatively small, the statistical power consumption is not realistic. Here, the main analysis is the change of the nitrate return flow and the aeration amount during the dynamic parameter operation compared with the fixed parameter operation. This change can be used to characterize energy savings. As can be seen from the figure 7 and 8, compared with the fixed parameters, the internal return flow of nitrifying liquid is reduced by 19.8%, the total air flow of aeration is saved by 10.9%, and the compliance rate of effluent is higher.

4. Conclusion

By regulating the air flow of the blower or the opening of the valve, the reflux pump and the dosing pump, our proposed system may achieve the required aeration, optimize the reflux and add drugs according to the requirements. Thereby, it may reduce the energy consumption of aeration and save the
operation cost.
Finally, we will test this system in a real WWTP. Via the data collection and analyst, we can verify our developed system.

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