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RESEARCH ARTICLE

# Advanced nitrogen removal using pilot-scale SBR with intelligent control system built on three layer network

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**Abstract** Since eutrophication has become increasingly severe in China, nitrogen and phosphorous have been the concern of wastewater treatment, especially nitrogen removal. The stabilization of the intelligent control system and nitrogen removal efficiency were investigated in a pilot-scale aerobic-anoxic sequencing batch reactor (SBR) with a treatment capacity of 60 $m^3/d$. Characteristic points on the profiles of dissolved oxygen (DO), pH, and oxidation reduction potential (ORP) could exactly reflect the process of nitrification and denitrification. Using the intelligent control system not only could save energy, but also could achieve advanced nitrogen removal. Applying the control strategy water quality of the effluent could stably meet the national first discharge standard during experiment of 10 months. Even at low temperature ($t = 13°C$), chemical oxygen demand (COD) and total nitrogen (TN) in the effluent were under 50 and 5 mg/L, respectively.

**Keywords** three layer network, sequencing batch reactor (SBR), advanced nitrogen removal, intelligent control

## 1 Introduction

With rapid development of the sewage treatment, our country has set stricter demands on sewage discharge. But the problem of eutrophication caused by nitrogen and phosphorus in water is not only unsolved, but also increasing worse. The highest discharge concentration of total nitrogen and phosphorus was added in 'the effluent standard of pollutant for city sewage treatment plants', newly issued in 2002. Also, stricter requirements were requested to the concentration of ammonia in effluent. It is obvious that the main illogicality for wastewater treatment has gradually changed from organic contaminant removal to nitrogen and phosphorus removal. However, some problems, such as low efficiency, high energy consumption, and instability, still exist in most sewage treatment plants. One of concerned research topics about wastewater treatment research is how to increase the efficiency of nitrogen removal and reduce the energy consumption.

At present, since sequencing batch reactor (SBR) process has the advantages of being easily controlled and neatly operated; it has been widely used in wastewater treatment. However, the most severe weakness of SBR process is the complexity of operation. So, the predominance of SBR process would not be exerted until realizing its automatization [1]. SBR usually operates with fixed time control, which may lead to tremendous energy and resources consumption owing to the influent fluctuation and system state variations. It is necessary to use higher level of process control and automation to operate SBR [1]. Recently, along with the rapid development of modern computer control technology, SBR process has been able to obtain much vital force and run to a kind of high efficiency wastewater treatment process. Two and/or three layer network and modern communication technologies were used to control wastewater treatment process [2]. Using three layer network technology can achieve real-time long-distance supervise and improve the precision of the deferent signal. Some researches have reported that for a nitrogen removal system, the on-line monitoring parameters, such as, oxidation-reduction potential (ORP), dissolved oxygen concentration (DO), and pH, indicated the end of the biodegradation processes [3–5]. Using these control parameters and three layer technology can optimize the operation of SBR. Up to now, it was found few observations of advanced nitrogen removal with intelligent control system built on three layer network in SBR for treating real wastewater.

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Therefore, the stabilization of the intelligent control system and nitrogen removal efficiency were investigated in a pilot-scale aerobic–anoxic sequencing batch reactor (SBR) with treatment capacities of 60 $m^3$/d.

## 2 Three-layer network technology

The three-layer network control system belonging to distributed control system (DCS) can be divided into the management level, control level, and locale level. This system generally consists of many industrial control computers and locale terminals. The locale control station, monitor station, operation station, management station, and engineer station are connected via network to achieve distribute control and centralized management.

Generally speaking, the three-layer network applied in industry control means the locale bus network, execution control network, and control management network.

Great deals of on-line monitor instruments are required on the spot. In order to improve the reliability and anti-jamming ability of the instrument system, and save the cost of installation, the instruments with locale bus network can be adopted. That is to say, all the instruments are linked on a twisted-pair. Data transmitting on the bus is packed and sinks check out it automatically. A great number of electrical and signal wires are saved, and the disturbance to signals is avoided. All of these form locale bus network—the most basic network.

The system of industry control mostly uses high-performance programmable logic controller (PLC) to improve the reliability of control system. According to switch and simulation quantum of input value, PLC feeds back signals and controls all the executors via high-speed periodic scan monitoring program. Thus, the automation of process can be achieved. Each PLC connects by optical fiber to form the second level executive control network. The control network and locale bus network are connected via net-bridge.

The monitoring computers in central control chamber adopt ischemia preconditioning (IPC) and are joined to the control network by communication module. Operators monitor the status of locale via human-machine interface; meanwhile, industrial server is used to connect with each station of the system and form a local area network via Ethernet. Ischemia preconditioning in central control chamber is also a station in local area network. Signals of the system status from control network are connected with database via the Rockwell software RSSQL. All mentioned above constitute the third intelligent control management network. The control system basing on the third network and database provide an effective platform for realizing an integrative management and control.

## 3 Composition and function of wastewater treatment intelligent control system in pilot-scale SBR

### 3.1 Brief introduction of the pilot-scale SBR system

The pilot-scale SBR was built in Beijing Beixiaohe Wastewater Treatment Plant. The surface of the steel SBR was covered with anticorrosive paint. Figure 1 shows the schematic diagram of the SBR system. An influent pump was installed in the effluent check-out well of primary sedimentation tank. Influent flow was controlled by a level gauge of floating ball or fixed time. At the end of influent, the blower was turned on to provide aeration. Dissolved oxygen (DO), oxidation reduction potential (ORP), and pH were monitored on-line to supervise the course of biochemical reaction. When the aerobic reaction was completed, the blower was stopped. Considering the removal of nitrogen and phosphorus in this

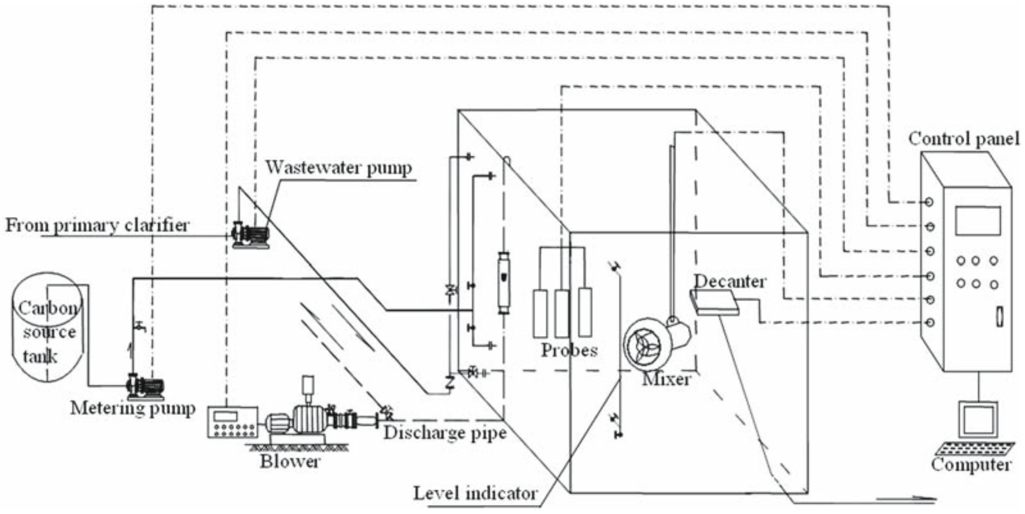

**Fig. 1** Schematic diagram and instructions of the pilot-scale SBR system

system, a mechanical mixer was used to provide adequate mixing during the anoxic/anaerobic period. Sometimes the metering pump was used to add carbon sources. According to the information of on-line sensors, the intelligent control strategy could exactly control the entire course of biochemistry reaction. After the whole reaction completed, the settlement stage began. The effluent was discharged by a decanter.

### 3.2 Composition and function of control system

According to the thought of three-layer network with distributed control, this pilot-scale intelligent control system set up three control layers, i.e., in-situ manual control layer, central control layer and remote monitoring control layer. Figure 2 shows the structure and function of the control system. The control system on-line monitored the influent quantity, DO, ORP, pH, and temperature. According to the on-line monitoring parameters, the control system adjusted and controlled the equipments to guarantee the effluent quality.

Field control equipments and simple instruments such as DO, ORP, and pH sensors constituted the in-situ manual control layer. Though operating field manual control box in workroom and switching on all kinds of equipments and executive units, the field control units, such as influent pump, blower, mixer, decanter, and other electrical equipments were controlled. In-situ manual control had the upmost priority.

Field central control layer is not only the key of achieving intelligent control, but also the hinge between remote management level and all equipments. Field central control layer in our pilot-scale system is composed of intelligent controller and its expanding templates, central control upper-computers, and so on. Physical parameters of monitoring control points are detected by corresponding simple instrument sensors or transmitters, and then transformed to electrical signals ranging from 4 to 20 mA. These signals were transmitted into intelligent controllers. Judgments were worked out based on the injunctions, which came from central control upper-computers or remote control station, and control strategy being fixed on controllers. Control signals, which could control the action of executive mechanism, were similarly transmitted by controllers.

The upper-computer, an industrial control calculating machine, acted as an engineer workstation, which is connected with field control station via the token ring network MB+. The operation system of upper computers used Windows 2000 and monitoring software applied industrial automation software. All of the stimulant menu pictures could display on upper computers, by which the overall equipments could be operated and controlled. The primary tasks of control system are as follows: collecting data and setting control parameters of SBR pilot-scale system; accomplishing data collection and controlling the configuration of automation system; programming online or offline and modification of set parameters; monitoring the procedure of production, including reveal the control menu pictures, real time data and whole figure of this system; drawing a trend curve of important parameters; showing the state of every equipment; error alarm; scientific statistic and memory of history data; assistant management of daily operation; providing strategy references.

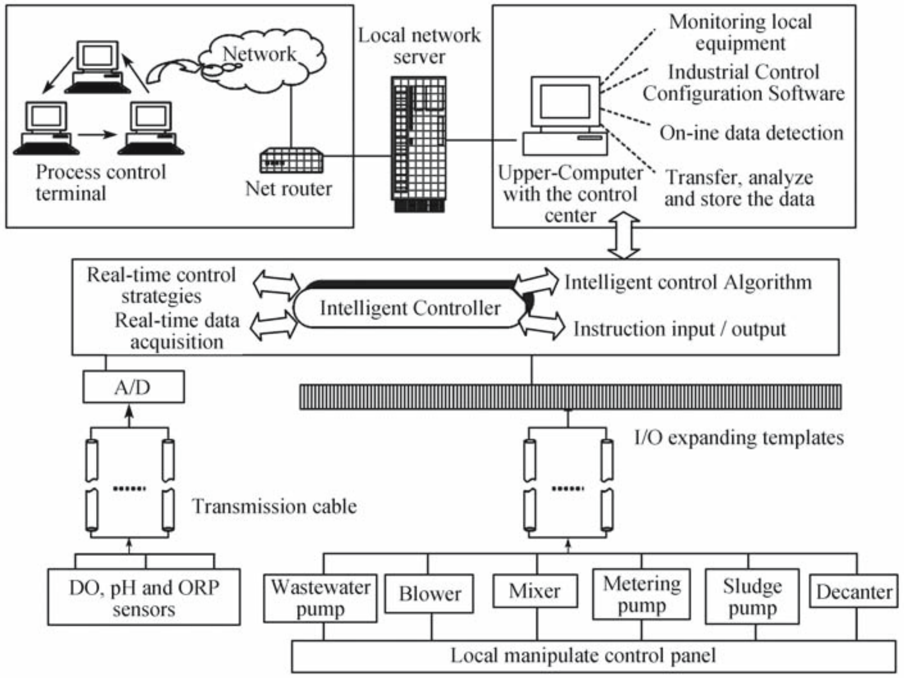

**Fig. 2** Schematic diagram and configuration of the control system

Remote control layer supports the remote terminal of TCP/IP (transmission control protocol/internet protocol). Through internet web explorer, local central control layer server can be interviewed to realize the remote supervise.

## 4 Buildup and examination of control strategies

Control strategies are the soul of entire control system. The primary research contents of this pilot-scale system focused on establishing control strategies of SBR process and testing its stability. The aim of controlling SBR process is to save cost and guaranteed the effluent quality. Traditional control strategy is mainly bases on fixed-time control. However, the fixed-time control strategies cannot adjust parameters timely corresponding with the quality of wastewater. Consequently, it is hard to achieve adaptive process control.

Traditional feedback control strategy could not be applied practically for the reason that on-line organic substance, nitrogen and phosphorus sensors have not been developed presently. Realization of intelligent control is the only way to give full play to the advantages of SBR.

### 4.1 Basic thoughts of intelligent control

Through long-term research and exploration of SBR process, some researchers [6–9] had chosen some process control parameters such as ORP, DO, pH, and so on. The control parameters had good relativity with organic substance and nitrogen removal. Figures 3 and 4 show the typical variations of DO, ORP, and pH for organic substrate removal and nitrogen removal in SBR.

As shown in Fig. 3, at the first 20 min, organic substances were oxidized. At the end of this stage, DO concentration increased from 0.3 to 1.5 mg/L. Subsequently, at the stage of nitrification, the ‘ammonia break point’ and the ‘ammonia valley point’ were appeared on the profiles of DO and pH. At the stage of denitrification (Fig. 4), ‘nitrate knee’ appeared on the profile of variation curves of ORP, while ‘nitrate apex’ emerged on the DO trend line at the end of denitrificaton. At characteristic points of nitrification and denitrification, aeration and mixing could be stopped in time, thus, the energy cost could be saved.

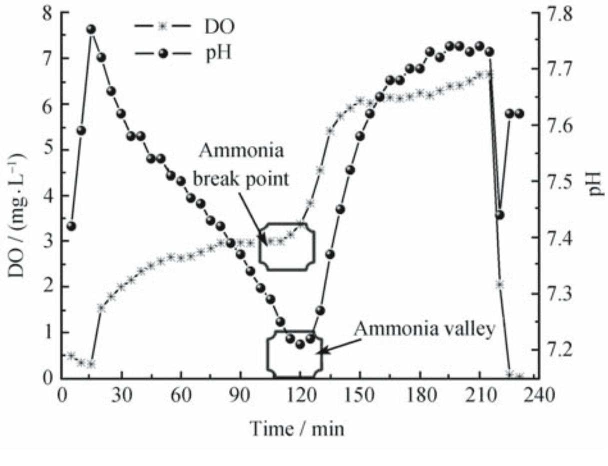

**Fig. 3** The typical variations of DO and pH for organic substrate removal and nitrification process in SBR process

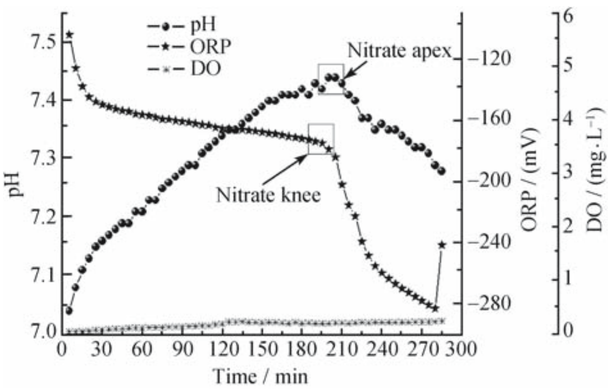

**Fig. 4** The typical variations of ORP and pH in SBR denitrification process

Through the analysis of DO, ORP, and pH variations in SBR, the results indicated that process control of organic substances and nitrogen removal could be achieved by detecting characteristic points on the variation curves of DO, ORP, and pH profiles. Using DO, ORP, and pH as fuzzy control parameters of organic substances and nitrogen removal, the fuzzy controller was built up. Our research group had basically accomplished the fundamental research of fuzzy control [10,11].

### 4.2 Operation scheme and procedure of intelligent control system

The operation mode used in the pilot-scale SBR mainly consisted of the following phases: filling, aeration, denitrification, settling, decanting, and idling. Configuration of intelligent control system in SBR is shown in Fig. 5. Interferential signals during the course of control were filtered, and the stabilization of the control system was examined in pilot-scale SBR. The results showed that COD and TN in the effluent met the national first discharge standard during the experiment (10 months) (Figs. 6 and 7). Even at cold temperature, the SBR process could be controlled by the intelligent control system. The variations of the online parameters and nitrogen during a typical cycle of SBR process are shown in Fig. 8. In Fig. 8, DO concentration in the mixture was comparatively high owing to the increase of oxygen transfer efficiency. Characteristic points on DO and ORP profiles did not appear at the end of nitrification, while the pH was not affected so much by temperature. The breakpoint was detected when nitrification was completed. All of results showed that the control system was stabled in winter.

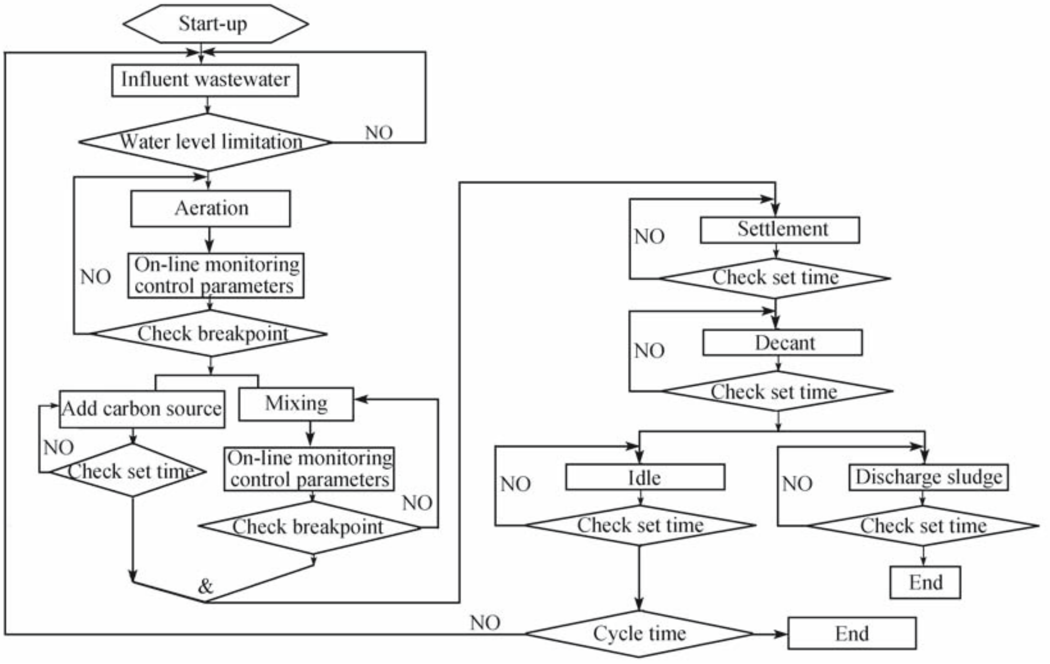

**Fig. 5** Configuration of intelligent control system in SBR

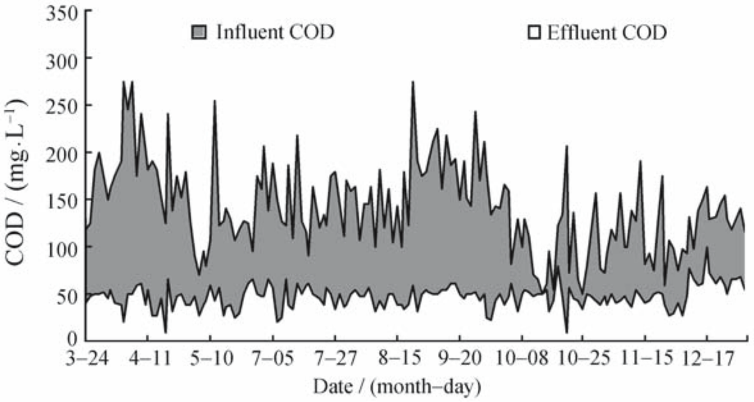

**Fig. 6** COD variations of the influent and the effluent in pilot-scale system

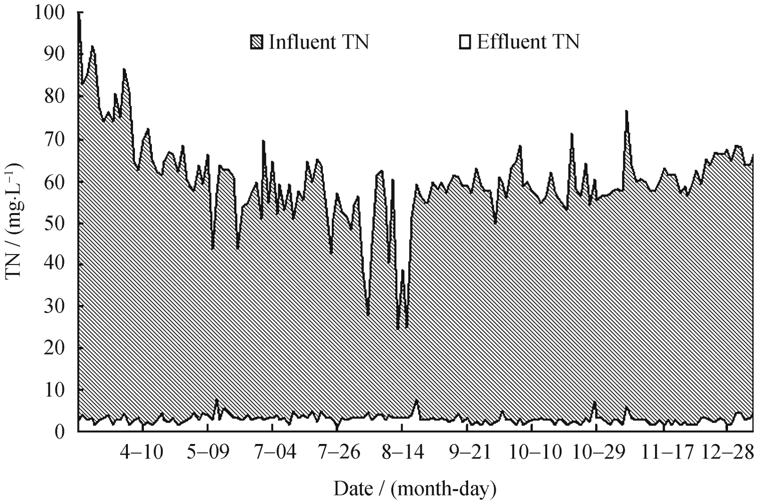

**Fig. 7** TN variations of the influent and the effluent in pilot-scale system

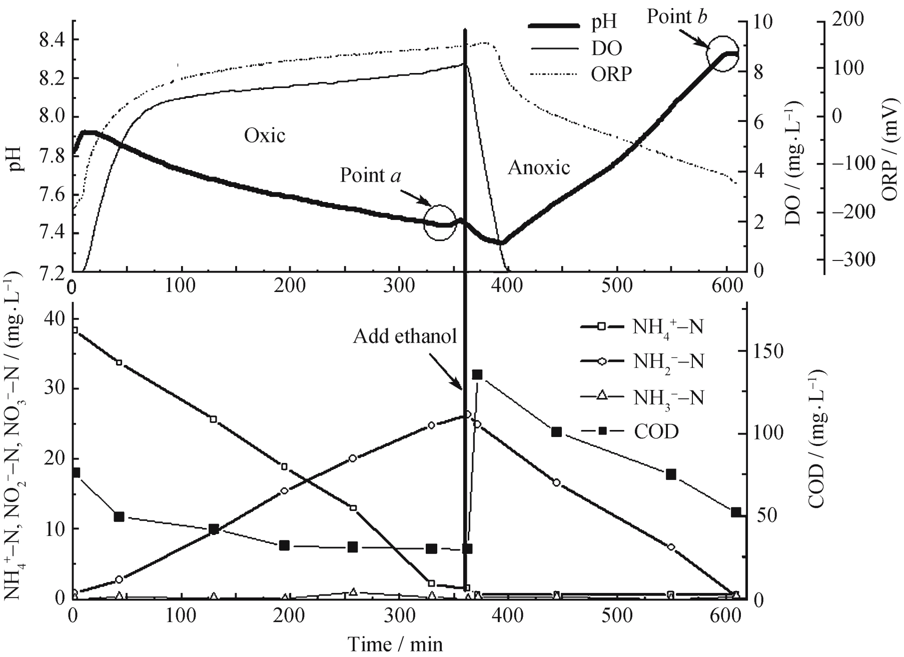

**Fig. 8** Profiles of on-line monitoring parameters and nitrogen in a typical cycle ($t$ = 13.1°C)

## 5 Conclusions

First, the stabilization of the intelligent control system and nitrogen removal efficiency was investigated in a pilot-scale aerobic-anoxic sequencing batch reactor (SBR) with a treatment capacity of 60 m$^3$/d.The control system based on three-layer network and database provided an efficient platform for the incorporation of management and control.

Second, characteristic points on the profiles of DO, pH, and ORP could exactly reflect the process of nitrification and denitrification. Using the intelligent control system not only could ensure the quality of effluent, but also could avoid excessive aeration, thereby saving energy and cost.

Third, applying the control strategy water quality of the effluent could stably meet the national first discharge standard during experiment of 10 months. Even at low temperatures, COD and TN in the effluent were under 50 and 5 mg/L, respectively. During the course of our experiment, this system could be controlled according to characteristic points of online parameters even at low temperature.

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