Development and application of Sequencing Batch Airlift Reactor for Domestic Sewage Treatment

Peng Chen1, 2, Chong Qiu3, Zhongjun Han1
1 College of Civil Engineering And Architecture, Zhejiang University of Water Resource and Electric Power, Hangzhou, 310081, Zhejiang, China
2 School of management, Fudan University, 200433, Shanghai, China
3 Zhejiang Shuanglin Environment Co., Ltd, 311100 Zhejiang, China
E-mail: chenpengtj@126.com

Abstract. Aiming at the demand of decentralized domestic sewage treatment in rural areas, Sequencing Batch Airlift Reactor (SBAR) for domestic sewage treatment was developed and applied for sewage disposal of an office building in shenjiadun village, Deqing, Zhejiang Province. The device doesn’t need to set up sedimentation tank and sludge reflux system. It has a good precipitation effect and only occupies a small area. In the aspect of control, it adopts the self-researched embedded software system. And it integrates GPRS /GSM /SMS /CDMA /Internet communication technology and high-precision electrical parameter measurement technology. The actual operation results show that the device can ensure sufficient contact between sludge and waste water. It can effectively remove BOD5, CODCr, ammonia nitrogen and total nitrogen from domestic sewage. And it has the advantages of low investment, low energy consumption, high automation and simple operation. Therefore, this device has important popularization value in the field of distributed treatment of rural domestic sewage.

1. Introduction
The research on Sequencing Batch Activated Sludge Process (SBAR) began in 1914 with Ardern and Locket. The world’s first intermittent activated sludge sewage treatment was built in Salford, England[1]. Due to the limitation of automation level at that time, especially the continuous expansion of industrial wastewater treatment scale, its disadvantages of operational difficulties and heavy workload were increasingly prominent, related research was abandoned early, it was used in practical projects rarely. Until the end of 1970s, R.Irvine formally put forward SBAR technology with the help of advanced automation technology and expounded its operation characteristics[2]. With the development of intelligent control technology and hardware equipment, the complex operation problems of sequencing batch reactor activated sludge process have become simple and flexible. The technology has developed rapidly and occupied a dominant position in the new process of domestic sewage treatment in various countries.

Domestic sewage discharge in villages and more remote areas is characterized by many points, wide area, small quantity and dispersion. So it is difficult to collect and manage, which means decentralized processing units with simple operation are needed urgently. SBAR technology has the advantages of high efficiency, low energy consumption, convenient installation, flexible combination and low operating cost. It has strong applicability in rural domestic sewage. However, at present the application of this technology in large sewage treatment plants has been more mature, but there is still some research space in the field of small domestic sewage treatment. It is difficult to maintain the
stability of the N\P in the influent water quality of the small domestic sewage treatment device, and the small device has certain requirements for intensive, automatic control and convenient maintenance. Based on this, aiming at the demand of decentralized domestic sewage treatment in rural areas, a domestic sewage treatment was developed. The device has the advantages of strong resistance to impact load and good sludge sedimentation. It doesn’t need to set up sedimentation tank and sludge reflux device and has a broad application prospect.

2. Device Profile

2.1. Composition of the apparatus
The schematic diagram of the SBAR device application is shown in Figure 1, which mainly includes two parts of the treatment tank and the intelligent integrated control cabinet, the parts inside the treatment tank are connected with the control cabinet through the air hose installed in the underground. The treatment tank integrates anaerobic tank and reaction tank, the two are partitioned through partitions. The equipment in the tank includes aeration pipe, air lift pipe, integrated sampler and inlet grille. The anaerobic tank can realize the functions of sewage storage, suspended solid precipitation, sewage mixing and partial denitrification. The reactor can realize the functions of nitrification and denitrification.

![Figure 1. Schematic diagram of SBAR device application](image)

Control cabinet includes all mechanical and electrical components, mainly including: air pump, valve unit composed of multiple solenoid valves, aeration device, controller containing GPRS communication module and so on. The controller adopts high performance 32-bit embedded RISC CPU hardware platform, which is developed by self-developed embedded software system, GPRS/GSM/SMS/CDMA/Internet communication technology and high precision electrical parameter measurement technology. It has the characteristics of high measurement accuracy, good reliability, large storage capacity and strong openness. Also it can meet the needs of sewage information collection, collection and management, monitoring, remote control and other applications.

2.2. Process Principle
The unit adopts the air lift sequencing batch activated sludge treatment process, the specific steps are "influent → denitrification → aeration → sedimentation → clean water discharge → excess sludge return". Each batch needs 4-6 hours, it can automatically switch different modes to control the device to achieve maximum safety treatment of sewage.
2.2.1. *Influent.* The wastewater is pumped from the anaerobic tank to the SBAR reaction tank through the airlift riser. Due to the solid matter is precipitated, only the liquid is pumped. The specially designed airlift pipe has a minimum liquid level to ensure that the solid material under the minimum level will not be transported to the aerobic tank. An overflow port is arranged on the partition board. When the sewage inflow is greater than the maximum liquid level, the sewage will overflow to the SBAR reaction tank. Due to the special design of the connection of the overflow port, the floating debris will not enter the SBAR reaction tank.

2.2.2. *Denitrification.* Denitrifying nitrogen removal process is biodegraded by specific microbial strains, intermittent aeration is used to stimulate denitrifying bacteria to convert nitrate into primary nitrogen.

2.2.3. *Aeration.* The sewage is aerated through the aeration pipe or aeration plate installed at the bottom of the tank body, and the air pump in the control cabinet provides the air needed for aeration. Intermittent aeration has two effects. One is providing oxygen for microbial metabolism and pollutant decomposition in activated sludge. And the other is mixing the sewage and microorganism well.

2.2.4. *Precipitate.* In this step, aeration isn’t carried out, activated sludge is precipitated under the action of gravity, water purification area is formed at the top and sludge layer is formed at the bottom.

2.2.5. *Discharge clean water.* The purified water (the sewage after biological purification) is pumped out through the air lift pipe. The specially designed air lift water system takes water from the middle clear water layer and it doesn’t extract suspended sludge.

2.2.6. *Remove excess sludge.* The excess sludge is pumped back to the anaerobic tank from the bottom of the SBAR reactor through the airlift riser. The whole process usually circulates four times a day, and the specific switching time and cycle times can be adjusted according to the actual situation. The system can automatically carry out low load detection to maintain the continuous growth of activated sludge and save energy consumption. The low load detection system is equipped with a pressure sensor, which can be used to detect the water level in the anaerobic tank. In the influent stage, if the preset level is not reached, the system will enter low load mode for 6 hours. In this mode, the system maintains sludge activity by occasional aeration. If the preset liquid level is not reached in the anaerobic tank after four consecutive measurements, the water in the reaction tank will be pumped back to the anaerobic tank to maintain sludge activity.

3. Application of the device

3.1. Demonstration site
The device is installed on the west side of an office building in shenjiadun village, Deqing County, Zhejiang Province. The design processing capacity is 5 m$^3$/d and the actual load is 91.6%. The source of sewage is domestic sewage discharged from daily consumption of staff in the office building.

3.2. Monitoring Index and Method
Water quality monitoring indicators include pH, CODcr, ammonia nitrogen, suspended solids, BOD$\text{s}$ and total nitrogen. The pH value is determined by portable pH meter. The suspended matter is determined by gravimetric method according to the requirements of “GB/T11901-1989”. Chemical oxygen demand is determined by dichromate method. Ammonia nitrogen is determined by Nessler's reagent spectrophotometry. Total nitrogen is determined by alkaline potassium persulfate digestion ultraviolet spectrophotometry. And BOD$\text{s}$ is determined by dilution and inoculation method.

3.3. Monitoring results and analysis
The water-quality index of the outlet and outlet of the device is shown in the table below.

**Table 1.** A slightly more complex table with a narrow caption.

| Sample point                  | pH  | COD Cr | NH₃-N | SS  | BOD₅ | TN  |
|-------------------------------|-----|--------|-------|-----|------|-----|
| Outlet of anaerobic zone      | 7.66| 211.0  | 32.9  | 26.0| 129.0| 74.8|
| Drainage outlet               | 6.91| 28.0   | 0.062 | 4.0 | 0.5  | 5.8 |
| Removal rate                  | -   | 86.7%  | 99.8% | 84.6%| 99.6%| 92.2%|

As can be seen from the above table, the removal efficiency of BOD₅, COD Cr, ammonia nitrogen and total nitrogen is high. The main water quality indexes of the effluent can meet the requirements of ‘Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB 18918-2002)’. There are different microbial populations in the sludge system with the change of pH, when the pH is between 5.0 and 6.0, the sludge bulking is easy to occur, but when the pH is between 7.0 and 8.0, there are a large number of microbial micelles, and it has good sedimentation performance[4]. In aerobic stage, microorganisms absorb ammonia nitrogen in wastewater. A small amount of ammonia nitrogen is transformed into biomass and other nitrogen-containing organic matter by assimilation, and most of ammonia nitrogen is converted into nitrate nitrogen through nitrification. Nitrate nitrogen is reduced to gaseous N₂ by denitrification under anaerobic and anoxic conditions and escapes from water[5]. Under aerobic condition, a large amount of phosphorus is quickly absorbed by microorganisms from wastewater and accumulated in cells in the form of polyphosphate. Under anaerobic conditions, the microorganisms decompose polyphosphate to obtain energy, and then release the activated sludge which is phosphate in anaerobic state to achieve the purpose of phosphorus removal. At the same time, the proper time sequence and operation conditions of SBR process provide better anoxic, aerobic and aerobic environmental conditions for nitrogen and phosphorus removal, so that denitrification can be realized under anoxic conditions, phosphorus release under anaerobic conditions and nitrification and excessive uptake of phosphorus under aerobic conditions, so as to effectively remove nitrogen and phosphorus.

The stability of sludge system directly affects the treatment performance of activated sludge. Rob found that the stability of activated sludge system can be quantitatively investigated by the total average filamentous length, sludge volume index and maximum specific oxygen consumption rate in unit sludge. However, the length of filiform bacteria and the volume index of sludge were directly related to sludge sedimentation. The device runs continuously for 18 days and is sampled once a day during stable operation. The measured water pollution is shown in Figure 2.

![Figure 2](image)

**Figure 2.** Sewage ratio during continuous operation of the plant

3.4. Operating energy
The rural population is more dispersed, the water consumption of a single household is less, and the sewage treatment scale is small, so the sewage treatment device is relatively more practical. For small devices, how to reduce energy consumption as much as possible is not only one of the key technical factors, but also a key factor of large-scale promotion.

In each component of the device, only air pump is used as power consumption equipment. The power consumption of a batch sewage treatment unit with a scale of 5 m³/d is 0.31 kW · h/m³. During the operation of the plant, there is no need to use chemical agents, so the cost of water treatment per ton is about 0.17 yuan.

4. Conclusion
Aiming at the demand of decentralized domestic sewage treatment in rural areas, a domestic sewage treatment was developed, and the device is applied in practice in Shenjiadun Village, Deqing, Zhejiang Province. It adopts the process of Sequencing Batch Airlift activated sludge treatment, the steps include "influent $\rightarrow$ denitrification $\rightarrow$ aeration $\rightarrow$ sedimentation $\rightarrow$ water purification discharge $\rightarrow$ excess sludge reflux". The actual operation results show that the treatment scale of the device is 5 m³/d, the actual load is 91.6%, the operation of the device can effectively remove the BOD5, CODCr, ammonia nitrogen and total nitrogen in domestic sewage, the device saves investment cost and it has lower energy consumption. The cost of water treatment per ton is about 0.17 yuan. At the same time, the device adopts the embedded software system developed by itself, which can realize high automation and easy to operate and maintain. Therefore, the SBAR device has the value of popularization in the field of decentralized treatment of rural domestic sewage.

References
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