

# Bio-chemical process for nitrogen and phosphorus removal by draining out anaerobic rich phosphate supernatant in ERP-SBR system<sup>\*</sup>

JI Fangying, XU Xiaoyi, LUO Guyuan

Faculty of Urban Construction and Environmental Engineering, Chongqing University, 400045, P.R China

**Abstract:** The method of fixed phosphate coming from anaerobic reactor by the auxiliary chemical process is applied in External Recycle Process-SBR (ERP-SBR). This process changes the model of draining out activated sludge in the traditional biological phosphorus removal system to discharge anaerobic poly-phosphate supernatant. This process eliminates the contradiction of control for Solid Removal Time (SRT) in process of biological nitrogen and phosphorus removal. It can obtain high removal efficiency of nitrogen(N) and phosphorus(P) in longer SRT. Experiment results show that: when SRT=50 ~ 80 d, TN=28.6~ 58.3 mg/L, TP=5.5~ 13.5 mg/L in influent, COD≤ 34mg/L, TN≤ 6.02 mg/L, PO<sub>4</sub><sup>3-</sup>≤ 0.23 mg/L in effluent. The amount of lime is only 5% of traditional methods. The phosphorus content in the chemical sludge is 12 %~15 % and the recycle of phosphorus can be realized easily.

**Keywords:** bio-chemical process; nitrogen and phosphorus removal; external recycle; phosphate supernatant; ERP-SBR system

## 1. Introduction

### 1.1 Theoretical basis

According to the theory of biological phosphorus removal, phosphate in sewage can be accumulated in aerobic sludge or anaerobic sewage by Phosphate Accumulating Organisms (PAOs) in the condition of which anaerobic and aerobic process take place alternatively. Effective biological P removal can be realized by discharging rich P sludge for traditional biological P removal process. The removal effect is associated to the content of P in sludge and the amount of discharging sludge. A short SRT is premise to attain high P removal efficiency in traditional biological p removal process<sup>[1]</sup>. In fact, P can also be accumulated by PAOs in anaerobic sewage and be removed effectively by physi-chemical methods, such as coagulating settlement and adsorptive filter etc. The paper studies the method specially, which can realize the P removal by discharging the supernatant with high content of phosphate.

### 1.2 Process introduction of bio-chemical N and P removal in ERP-SBR

In order to study on P-fixation of anaerobic rich P sewage, a new process namely External Recycle Process aerobic sludge in SBR (ERP-SBR) is brought

forth in paper. The experimental apparatus and process are shown in Fig.1 where the three main reactors are SBR, Anaerobic P-Release Reactor (APRR) and Chemical P-Removal Reactor (CPRR). During the operation, SBR adopts traditional way of biological N and P removal, and part of P-uptaking sludge is discharged into the APRR at the end of each period. After finishing P-release, the sludge is pumped back to SBR to perform P-uptake. Anaerobic supernatant is recycled to SBR joining bio-chemical process after supernatant with high content of P has been fixed by chemical precipitation.

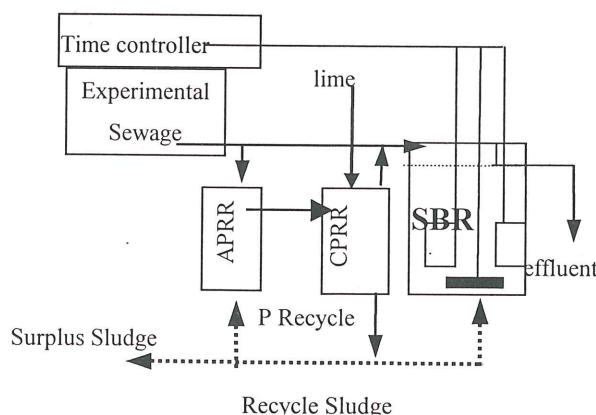


Fig.1 Flow schematic diagram of ERP-SBR system

### 1.3 Innovations and characteristics of ERP-SBR

1) SRT of biological N and P removal system can

JI Fangying (吉方英): Female; Born 1964; PhD candidate; Asst. Prof.; Main research scope: water pollution control theory and technology.

<sup>\*</sup> Supported by Founded by natural science foundation of China.(50278101)

only depend on N removal requirement in ERP-SBR system.

2) External recycle process of aerobic sludge have high MLSS [2], which can increasing the sludge volume load.

3) External recycle process of aerobic sludge not only favors aerobic stabilization of activated sludge, but also can resolve the problem of P-fixation and disposal of biological sludge in traditional wastewater treatment.

Table 1. Influent characteristics after addition of other elements

| Component Index | CODcr<br>/(mg/l) | TN<br>/(mg/l) | NH <sub>3</sub> -N<br>/(mg/l) | TP<br>/(mg/l) | PH  | T<br>/°C |
|-----------------|------------------|---------------|-------------------------------|---------------|-----|----------|
| Concentration   | 238~694          | 28.6~58.3     | 20.6~51.4                     | 5.5~13.25     | 7~8 | 22~30    |

## 2.2 Experimental apparatus and process

The whole equipment consists of three vessels, the main reactor SBR with effective volume of 18 L, anaerobic P-release reactor 3L, and chemical P removal reactor 2L.

In SBR, filling water ratio is 0.61, and operation cycle is 8 hours. Each cycle consist of 2 hours mixed filling and anaerobic stage, 3 hours aerobic stage, 1.5 hours anoxic stirring time, 30 minutes later aerobic stage, 30 minutes settling and drawing time and 30 minutes idle time.

There is no extra sludge discharge in ERP-SBR, and the sludge loss comes from the analysis test. The SRT is about 50~80 days, and MLSS is 6.5~7.5g/L. Sludge load is 0.10~0.13kgCODcr/kgMLSS · d in the study with steady operation.

## 3. Results and disscution

### 3.1 Removal capacity of CODcr

CODcr varies periodically with an alternative process of anaerobic, aerobic and anoxic conditions in SBR reactor. The evolution is shown in Fig.2. It shows about 68% CODcr is removed in anaerobic stage and they are stored in microorganism cells in the form of PHB in order to provide carbon resource for aerobic oxidation and denitrification. COD removal efficiency of ERP-SBR system in steady operation is shown in

## 2. Material and Method

### 2.1 Influent characteristics

The campus sewage after addition of starch, glucose, milk powder, NH<sub>4</sub>Cl, KH<sub>2</sub>PO<sub>4</sub> is used as experimental sewage in order to make it similar to typical municipal wastewater of middle concentration. Average values of the analyzed variables are presented in table 1.

fig.3, the figure shows the system has good COD removal efficiency. When CODcr is 238~694mg/l in influent, CODcr ≤ 34mg/l in effluent, the average rate of CODcr removal is 95.08%.

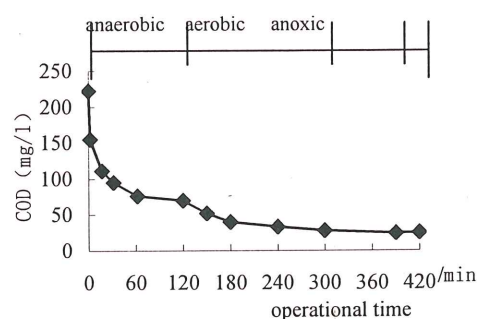


Fig.2. The relation between COD and time for each cycle of 8 hours

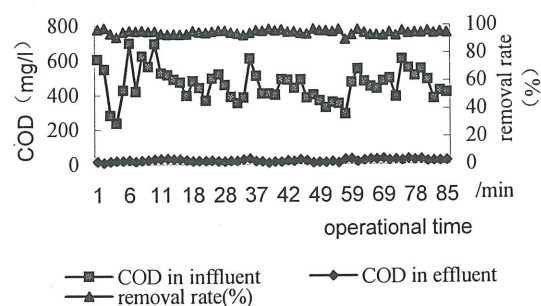


Fig.3. Removal efficiency of COD in ERP-SBR

### 3.2 Transfer and removal efficiency of N

The change rules of DO, NH<sub>3</sub>-N and TN and removal efficiency of NH<sub>3</sub>-N and TN in ERP-SBR system are shown in fig.4 and fig.5 respectively. These figures

show that: (1) DO rises slowly in earlier aerobic time, and  $DO < 1\text{mg/l}$  after aeration of 90~120min which leading to the concentration of  $\text{NH}_3\text{-N}$  falling quickly near to zero and then DO increases quickly. (2) The loss of about 68% TN happens in aerobic phase, especially in early aeration time when DO is limited. The tests find that the loss of TN always go with the fall of the concentration of  $\text{NH}_3\text{-N}$  and concentration of TN is relatively steady in later aeration time after the concentration of  $\text{NH}_3\text{-N}$  near to zero. (3) The anoxic

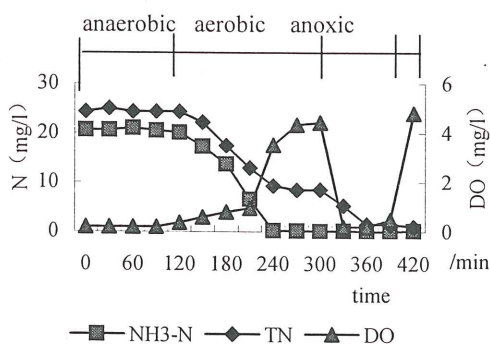


Fig.4 The relation between N, DO and time

### 3.3 Evolution and removal efficiency of P

The change of P-uptake and P-release in SBR is shown in fig.6. It shows the P release rate declines obviously after 1 hour. In early aeration time, the concentration of P decreases sharply at the rate of  $1\text{mg/min}$  though the concentration of DO is rather low. The concentration of  $\text{PO}_4^{3-}$  is lower than  $1\text{mg/l}$  after one-hour aeration, and almost approaches to zero in later aeration time. The efficiency of P removal in ERP-SBR system is shown in fig.7 during steady operation for three months. It shows that  $\text{PO}_4^{3-}$  usually approaches to zero, Maximum is  $0.23\text{mg/l}$ , average value is  $0.08\text{mg/l}$  and removal efficiency is 98.8% when  $\text{PO}_4^{3-}$  is  $5.5 \sim 13.25\text{mg/l}$  in influent.

### 3.4 Chemical P-fixation

The reaction production of anaerobic supernatant with high content of P and lime is phosphorite and calcium carbonate. The dosage of lime depends on the concentration of phosphate and carbonate in influent (the latter expressed by alkalinity in municipal sewage and unit is  $\text{mgCaO/L}$ ). When municipal wastewater with low concentration of P is treated with chemical method, the dosage of lime usually lies on alkalinity not

stage is inevitable link to ensure good efficiency of TN removal. Fig.5 shows when there is no anoxic phase (0~34d) in ERP-SBR system, TN in effluent is  $67 \sim 18.5\text{mg/l}$  and its average removal efficiency is 68.3%; When there is one hour anoxic phase (35~41d), TN in effluent is  $5.9 \sim 13.2\text{mg/l}$  and its average removal efficiency is 75.7%; When anoxic time increases to 1.5h (41~85d), TN in effluent is  $1.06 \sim 6.02\text{mg/l}$ , average is  $3.98\text{mg/l}$  and its average removal efficiency is 89.8%.

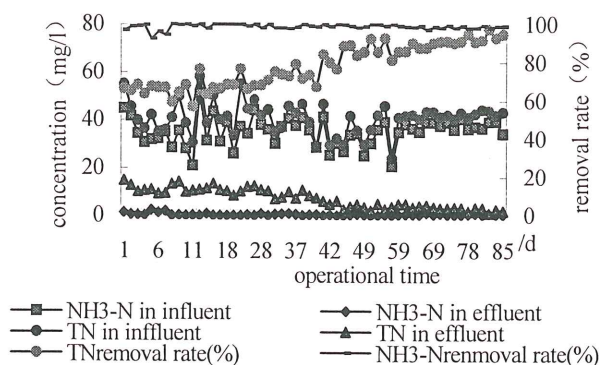


Fig.5 Removal efficiency in ERP-SBR system

the concentration of phosphate [3]. It leads to low using rate and high cost, and obstructs the application of chemic P removal process. However, The using ratio of lime is increased remarkably in chemical P-fixation process. The results are shown in fig.8 and fig.9.

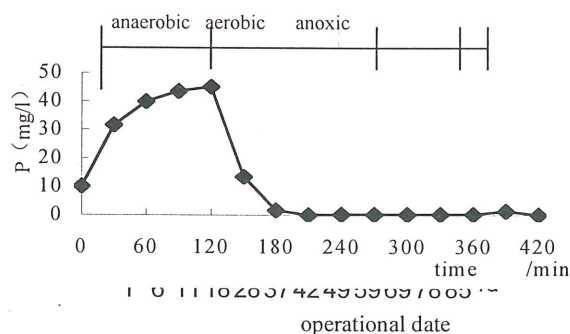
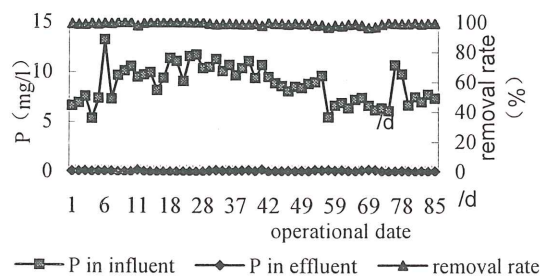


Fig.7 Removal efficiency of P in ERP-SBR

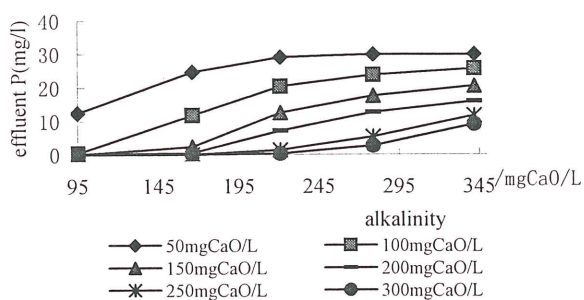


Fig.8 Alkalinity influence on P chemical removal in anaerobic rich phosphate supernatant

The figures shows that (1) If the sewage have the same concentration of P and different alkalinity, the same p removal efficiency needs different the dosage of lime. Moreover, the more alkalinity, the more dosage. (2) Only small dosage of lime can produce obvious chemic precipitation for supernatant with high content of P. When the concentration of P is reduced from 52mg/l to 5mg/l and 0.5mg/l in routine alkalinity conditions (100~ 150mgCaO/L), the dosages are 100~ 150gCaO/m<sup>3</sup> supernatant and 200~ 250gCaO/m<sup>3</sup> supernatant respectively. If normal sewage with P is reduced directly to 0.5mg/l with chemic method, the dosage of lime increases further to 259~ 300 gCaO/m<sup>3</sup> due to super-saturation. (3)Because of enhanced anaerobic P release, only part of anaerobic sewage (about 10% the total amount of sewage) is participated to P-fixation by chemical dosage. Moreover, these sewage after precipitation will continue to join biochemical reaction in SBR system and so the concentration of P can be about 5mg/l not 0.5mg/l. Of course, the amount of lime decreases greatly. Hence, the dosage of lime is 10~ 15gCaO per ton initial sewage in ERP-SBR and is only equal to 5% dosage of low P sewage. (4) The ratio of P reaches 12~ 15% in chemic sludge coming from chemic precipitation of anaerobic supernatant, which is in favor of recycle of P.

#### 4. Analysis on influence factors to ERP-SBR system

##### 4.1 Control of DO

In oxygen-restricted condition, nitrification is limited easily in nitrous period and production of NO<sub>2</sub><sup>-</sup> due to thermodynamic instability can oxidate NH<sub>3</sub>-N to N<sub>2</sub> finally under the function of catalytic inducement of biological enzyme. So biological removal of N by aerobic microorganism always goes with degradation

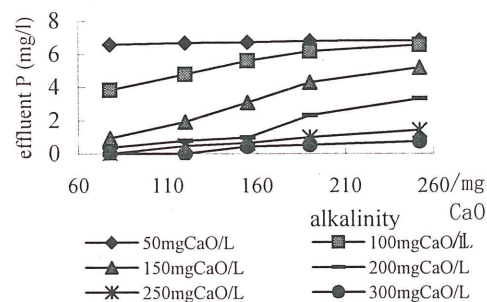


Fig.9 Alkalinity influence on P chemical removal in normal sewage with phosphate

of NH<sub>3</sub>-N in oxygen restricted condition. The tests find that enhanced aeration in system leads to decline of the ability of N removal, or even disappear in aerobic time. To ensure good aerobic N removal efficiency, it is very important to control aeration strengthen, that is to control DO <1mg/l in 1.5~ 2 h aeration time. Actually, long SRT and high MLSS are in favor of becoming this perfect oxygen restricted condition in ERP-SBR system.

##### 4.2 The degree of P-fixation in chemic P removal reactor

P removal is realized by chemic precipitation in ERP-SBR system, so the degree of P-fixation influences directly degradation ability and P removal efficiency of wastewater treatment. The excess P-fixation will lead poly-P in system to decrease greatly, and the ability of storing energy of PAOs to reduce. On the other hand, low degree of P-fixation induces poly-P to increase and leads high concentration of P when P absorption attains balance. To ensure activity of microorganism, the degree of P-fixation should be based on substantial equation in steady operation. It can be expressed as follows:

P in influent = P in effluent + P in surplus sludge + P in chemical sludge

$$P = QC_{T0} - QC_{eff} - \frac{XQC_s \times 10}{\theta_c \lambda n}$$

where P is the P amount in chemical precipitation per cycle (g); C<sub>T0</sub> and C<sub>eff</sub> are the concentration of TP in influent and effluent (mg/l); C<sub>s</sub> is the mass percentage of P in surplus sludge (%); Q is the quantity of influent per cycle (m<sup>3</sup>); X is MLSS (g/l); λ is the ratio of influent; θ<sub>c</sub> is SRT and n is the number of operational period per day.

Obviously, it is not important that P is removed by discharging surplus sludge in ERP-SBR system and

extending SRT can obtain good nitrification and denitrification. Because PAOs grows slowly[4], extending SBR is in favor of increasing the ratio of PAOs and enhancing the effect of aerobic P absorption. The test of ERP-SBR system shows that PAOs still has good ability of P absorption and aerobic denitrification in system with long SRT of 50~80 d.

#### 4.3 Enhance of anaerobic P release

To keep P balance in ERP-SBR system, the amount of anaerobic supernatant with high content of P decreases with increase of P concentration in chemical P removal reactor. So improvement of anaerobic P-release ability of sludge can reduce operation cost of system. It is usually thought that anaerobic P release ability is depended on character of sewage instead of anaerobic condition itself, hence, the content of VFAs in influence directly P concentration in supernatant. The test finds that PAOs absorbs 1mol HAc and releases 1mol P, namely, 2.03mg HAc-COD absorption is concomitant with 1mg P-release[5]. Relatively high content of VFAs in sewage can produce high concentration of supernatant and part of supernatant is drained directly into the chemical P removal reactor. If content of VFAs is low, in order to sure anaerobic sewage of chemical treatment has high concentration of P, part aerobic sludge should be recycled to anaerobic P-released reactor to enhance anaerobic P release of part sludge by adding HAc or first settling sludge with high content of VFAs from primary settling tank.

#### 5. Conclusions

1) ERP-SBR system changes the model of traditional biological P-fixation to chemical P-precipitation for ARPS and solves the contradiction of different SRT

requirement in biological P and N removal system. The test shows the system with chemical P-fixation of RPS attains better simultaneous N and P removal efficiency than traditional biological P and N removal system.

2) Long SRT and high MLSS are in favor of becoming DO restricted environment. When  $DO \leq 1$  mg/l in 1.5~2 h after the beginning of aeration in SBR reactor, 68 % N can be removed by aerobic denitrification in system.

3) ERP-SBR system adopts anaerobic treatment for all sludge and enhanced anaerobic treatment for part sludge to increase P concentration in anaerobic sewage of chemical treatment and to improve activity and aerobic P absorption ability of PAOs.

4) The dosage of lime in ERP-SBR system is only 5 % of low P sewage in the process. It improves chemical medicament efficiency greatly and the ratio of P reaches 12~15 % in chemic sludge which is in favor of recycle of P.

#### References

- 1 Zheng Xingcan, Li Yaxin, Wastewater N and P removal technology, chemical industry publishing house, 1999
- 2 Ji Fangying, Luo Guyuan, et al. Biological Phosphorus Removal Capability in SBR System Using External Recycle of Activated Sludge, China Water & Wastewater, 2002,18(5):1-5
- 3 Mogens H, Poul H, et al, Wastewater Treatment Biological and Chemical Processes (Second Edition), 1997
- 4 M.C.M.van Loosdrecht, C.M.Hooijmans, et al, Biological phosphate removal processes. Appl Microbiol Biotechnol. 1997, 48:289~296
- 5 Yang Qin, Ji Fangying, Study on Phosphorus Discharge Capability of External Recycle of Activated Sludge in SBR System Using External Recycle of Activated Sludge, Chongqing Environmental Science, 2002, 24(6): 57-59, 62.