The removal of phosphate in rural domestic wastewater with a SBBR by micro-bubble technology

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Abstract. Because of the large content of organic matter as well as nitrogen, the competition between phosphate accumulating organisms (PAOs) and glycogen accumulating organisms (GAOs) was serious in wastewater. This phenomenon led to biological phosphate removal in a SBBR with micro-bubble technology was not quite effective. Meanwhile, it can be concluded that the high dissolved oxygen (DO), ammonia nitrogen(NH4+), sludge solubilization affect the biological phosphate removal seriously. This paper was aimed to provide some information’s to improve the phosphate removal in the next step.

1. Introduction
Sequencing batch biofilm reactor (SBBR), which was first proposed by Wilderer in 1992[1], is considered as one of the most important technology in rural sewage treatment. Since then, the first SBBR demonstration project was established to exploring its operating mechanism in the Ingolstadt sewage treatment plant in Germany [2]. Aeration is one of the most important parameter for SBBR to improve its engineering effect; also, the process of oxygen transfer is the key factor for restricting the aeration process.

According to the Young-Laplace equation, the additional pressure in the bubble varies directly with surface tension and inversely with diameter [3]. In other words, the pressure in the bubble is increasing with the decreasing bubble size, which can greatly improve the driving force of its transmission. Due to the small diameter of micro-bubbles(less than 50µm), it will shrink and collapse beneath the water surface, which caused better driving force of transmission than conventional bubbles [4]. At the same time, the specific surface area of the gas-liquid during oxygen transfer is effectively increased with the dissolution of micro-bubbles, which is benefit for the mass transfer [5, 6]. Moreover, the dissolution of micro-bubbles also causes an increase of the contact area and contact time, which could facilitate bubbles, dissolved in water and enhances the concentration of dissolved oxygen in water. To some extent, it overcomes the oxygen insolubility in water, demonstrating that micro-bubbles have unique advantages in gas-liquid mass transfer.

In this study, the performances of the micro-bubble generator were tested to investigate the mechanism of biological phosphate removal. The objectives of this paper were to provide some information’s to improve the phosphate removal in the next step.
2. Materials and Methods

2.1. Experimental Equipment

The operation of the device is described in detail in the following combination:

![Figure 1. Experiment reactor.](image)

A schematic diagram of the experimental equipment is provided in Figure 1. The experimental system includes three parts: the water-bath system, the reactor and the aerator. The temperature was maintained at 35°C throughout the experiment using a thermo jacket. A laboratory-scale reactor with an internal diameter of 250 mm and a working volume of 30 L was fabricated from Plexiglas, which is not easily broken or deformed and allows easy observation of the biofilm carriers inside the reactor.

| Device name                  | Model  | Number | Function                                       |
|------------------------------|--------|--------|------------------------------------------------|
| Micro-bubble generator       | B&W-37 | 1      | Generates micro-bubble in the reactor          |
| Peristaltic pump             | BT600-2J| 4      | Controls the flow rate and flow direction of wastewater inlet and outlet |
| Rotor flow meter             | LZB-4  | 1      | Controls the flow rate of gas to the reactor   |
| Microcomputer control switch | GND-1  | 4      | Controls the opening and closing of each reactor at fixed time |

Table 1. Facilities of simulative test equipment.

The mean diameter of the bubbles from the microbubble system was below 0.42 μm (as shown in Figure. 2); their numerical density exceeded $2.9 \times 10^4$ counts/mL at a gas flow rate below 0.5 L/min.

![Figure 2. Micro-bubble diameter distribution under stable conditions (supplied by Benzhou New Technology (Nano Bubbles) Promotion Co.).](image)
2.2. Material Sources
The prepared wastewater included 0.42 g l\(^{-1}\) glucose, 3.83 mg l\(^{-1}\) K\(_2\)HPO\(_4\), 4.57 mg l\(^{-1}\) KH\(_2\)PO\(_4\), 95.35 mg l\(^{-1}\) NH\(_4\)Cl, 0.15 mg l\(^{-1}\) MgSO\(_4\).

2.3. Analysis of the Project and Method
Total phosphate was measured according to Chinese SEPA Standard (State Environmental Protection Administration, 2002).

3. Results and Discussion
In this study, the phosphate removal efficiency was very low. As shown in Figure 3, the concentration of TP was much higher than that in influent when hydraulic retention time (HRT) is 8 h. Also, the removal of TP in the reactor was not ideal. To better analyze the failure of phosphate removal, the mechanism was discussed with the following perspectives.

Table 2. Water quality indicators.

| Indicators | pH | DO (mg/L) | COD\(_{5}\) (mg/L) | NH\(_4\)-N (mg/L) | PO\(_4\)-P (mg/L) |
|------------|----|-----------|-------------------|-----------------|-----------------|
| Numerical  | 7.03 | 6.0~7.0 | 500.0 | 80.0 | 3.0 |

![Figure 3. Changes of TP in the reaction process](image)

3.1. The Temperature
The temperature, which affected the quantity and activity of microorganisms, influences the formation of the biofilm seriously. In order to multiply the biofilm and increase the microbial activity rapidly, the appropriate reaction temperature is important.

Many studies have shown that GAOs increased and gradually replaced as the dominant bacterial group when the concentration of organic matter was higher [7]. GAOs can utilize glycogen as an energy source without releasing phosphate in the anaerobic condition, whereas not synthetize polyphosphate compound in the aerobic condition [8]. If the PAOs were replaced by the GAOs, the phosphate removal efficiency would be greatly reduced. Previous work has shown that many factors could lead to a high accumulation of GAOs; the organic matter was mostly utilized by the GAOs rather than the PAOs when the temperature in the reactor was higher than 30°C [9].

As reported by Wan et al, the removal of chemical oxygen demand (COD) increased and the phosphate removal decreased with increasing reaction temperature in anaerobic leachate digestion in a SBBR[10]. It can be concluded that the quantity and activity of microorganism were strengthened within a certain range. Contrary to the COD, the phosphate removal (76%) was lower at 25°C than that (86.4%) at 13°C, no matter in the anaerobic condition or in the aerobic condition[11]. It can be speculated that the PAOs are psychrophilic bacteria, therefore, the GAOs became the dominant bacterial for the temperature of 35 °C in the micro-bubble reactor[12].
3.2. Dissolved Oxygen
Additionally, the microorganisms must be cultured in anaerobic and aerobic conditions, which resulting in the adsorption and accumulation of microorganisms during the phosphate removes process [13]. The phosphate removal process in a conventional biological phosphate removal system is realized by phosphate accumulation in the sludge. PAOs absorbed phosphate from wastewater in aerobic conditions, whereas hydrolyzed polyphosphate into orthophosphate and released it back to wastewater in anaerobic conditions [14]. Therefore, the absorption and release of phosphate are mainly determined by the concentration of DO in wastewater.

It was indicated that PAOs was always existing when the concentration of DO was changed between 2.5–3 mg L\(^{-1}\). Meanwhile, the PAOs could release phosphate by utilizing the degradable dissolved organic matter as carbon source in an anaerobic condition (DO<0.2 mg L\(^{-1}\))[15]. In this study, the concentration of DO was too high to dephosphorize in the micro-bubble reactor.

3.3. Ammonia Nitrogen (NH\(^4^+\))
When a large amount of NH\(^4^+\) exists in influent, it can affect the release and absorption of phosphate during the phosphate removal process. The denitrification rate is faster than the rate of release of phosphate, which would consume the degradable dissolved organic matter as carbon source, resulting in the PAOs is unable to obtain sufficient carbon source to allow for the phosphate of phosphate[16].

With the increasing concentration of the NH\(^4^+\) in influent, SBBR reduced the TP removal from 93.5% to 38.1%. The results meant that the NH\(^4^+\) was not conducive to the TP removal [83]. Meanwhile, the removal of phosphate was significantly inhibited when the nitrate concentration was greater than 1.5 mg L\(^{-1}\) in influent [17]. Therefore, it can be concluded that ammonia nitrogen is also a important factor affecting the phosphate removal.

3.4. The Sludge
Compared with the Sequencing Batch Reactor Activated Sludge Process (SBR), the phosphate removal of SBBR is not ideal. Due to the introduction of carrier used in SBBR, the microbial community was distributed throughout the carriers relatively evenly and the sludge in SBBR was more stable. Therefore, a thicker biofilm formed on the carriers in the reactor, and the main mechanism of dephosphorization occurred through phosphate absorption by the microorganisms and the sludge. Nevertheless, the SBBR hardly achieved phosphate removal by eliminating the rich phosphate sludge. In addition, the micro-bubbles dissolve sludge and the organic substances released from the carriers in the reactor, resulting in a very small quantity of sludge, which prevented the phosphate removal process [18].

It can be concluded that the low phosphate removal in SBBR was resulted from the high reacting temperature, DO and NH\(^4^+\), as well as the sludge solubilization.

4. Conclusion
Due to the competition between PAOs and GAOs in the micro-bubble reactor, the removal of phosphate is much lower than expected in this study. Moreover, the high DO, ammonia nitrogen (NH\(^4^+\)), sludge solubilization affects the biological phosphate removal seriously. This paper was aimed to provide some information’s to improve the phosphate removal in the next step. This phenomenon suggested that biological phosphate removal in a SBBR with micro-bubble technology was not quite effective.

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