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Impacts of sludge retention time on the performance of an algal-bacterial bioreactor

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HIGHLIGHTS

- AOB were effectively washed out but cyanobacteria existed at SRT of 10 d.
- A low SRT resulted in more PAOs but with less phosphate removal.
- SRT did not have significant impacts on ammonium removal.
- A high SRT resulted in a better reactor stability.

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ABSTRACT

The impacts of sludge retention time (SRT) on the performance of algal-bacterial reactors were evaluated. Membrane reactors A and B were applied at SRTs of 10 days and 20 days, respectively. A low hydraulic retention time, eight hours, was intentionally applied for showing the effect of SRT. Results showed that biomass concentration did not exceed 2 g/L. Without external oxygen supply, the chemical oxygen demand (COD) removal efficiencies were approximately 60% and 50% at the SRTs of 20 days and 10 days, respectively. Ammonium removal efficiencies were approximately 50% in the two reactors. Slight aeration increased the COD and ammonium removal efficiencies to approximately 90% and 100% respectively in the reactor B, whereas the improvements in the reactor A were less. Ammonium oxidation bacteria (AOB) were effectively washed out by applying the SRT of 10 days, whereas much more AOB were detected in the reactor B. The presence of phosphate accumulation organisms in continuously illuminated reactors was proved by high throughput sequencing. Strikingly, the reactor B showed higher phosphate removal efficiency at the conditions that more AOB, which competed for ammonium against algae, were detected in the reactor B. Therefore, improving phosphate removal by washing out AOB via SRT control is not feasible. Furthermore, the SRT also had significant impacts on algal ecology. Microscopic examination showed that *Oscillatoria* sp., the most active algae, dominated in the reactors, whereas the low SRT washed out *Chlorella* sp., *Diatoms* sp., *Closterium* sp. Generally, experimental results suggested that SRT of 20 days showed better reactor performance.

1. Introduction

Wastewater treatment by algal-bacterial systems attracts much attention recently as external mechanical aeration is not necessary. Nevertheless, current algal-bacterial reactors are with low efficiencies and are often applied to polish effluent of reactors [1–3]. Suspended algae are hard to be retained in reactors, which results in low algal concentrations and low reactor activities. If concentrations of algae and bacteria in reactors can be increased significantly, algal-bacterial reactors have a potential to directly treat domestic wastewater. By using a single algal-bacterial reactor, chemical oxygen demand (COD) and ammonium were efficiently removed from wastewater, whereas the removal efficiency of phosphate was merely 40% [4]. A higher phosphate removal efficiency can be achieved if ammonium concentrations in the influent are much higher than that in typical domestic wastewaters. If the phosphate removal efficiency can be increased to a high level, the efficient treatment of domestic wastewater can be achieved in a single reactor without external oxygen supply.

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According to the stoichiometry of algae growth, the removal of 1 mg P requires 5.4–7.2 mg NH_4^+-N [5,6]. However, ammonium and phosphate concentrations in medium strength domestic wastewaters typically are 40 mg/L and 10 mg/L, respectively [7]. Apparently, influent ammonium is not sufficient to result in a complete phosphate removal by algae. Furthermore, ammonium oxidation bacteria (AOB) compete for ammonium against algae, which reduces the capacity of phosphate removal by algae. Therefore, when algal-bacterial consortia, either are suspended or in the forms of biofilm, are applied to treat wastewater, it is difficult to achieve efficient simultaneous COD, ammonium and phosphate removal [8–10].

Applying a suitable sludge retention time (SRT) may reduce the concentration of AOB in a suspended algal-bacterial consortium. Through the decrease in AOB concentration, algae can have access to more ammonium, which should result in more oxygen production and phosphate removal by algae. *Nitrosomonas* are typical ammonium oxidation bacteria. The maximum growth rates for *Nitrosomonas* are between 0.55 d^{-1} and 1.2 d^{-1} [11–13]. Similarly, the growth rates for each species of algae vary significantly. The maximum growth rates for cyanobacteria, diatoms and chlorella are 6.12 d^{-1} [14], 2.25–2.5 d^{-1} [15,16], 0.79–5.9 d^{-1} [17–19], respectively. Considering the difference in the maximum growth rate between algae and AOB, SRT may play a significant role in determining ammonium removal efficiency of an algal-bacterial reactor.

Phosphate accumulation organisms (PAOs) are able to accumulate poly-phosphate with concentrations of up to 0.38 g P/g biomass that is higher than 0.02 g P/g biomass in normal activated sludge [20]. Low effluent phosphorus concentrations can be achieved via SRT control in different full-scale wastewater treatment plants in which enhanced biological phosphorus removal is applied. As for algal-bacterial reactors, the discharge of algae and PAOs from reactors is expected to have impacts on phosphorus removal. However, the effects of SRT on phosphate removal in algal-bacterial reactors have been scarcely reported. Valigore, Gostomski, Wareham and O'Sullivan [21] evaluated the impacts of COD removal and biomass settler ability of algal-bacterial biomass with SRTs varied from four to 40 days. However, the impacts of SRT on the nutrient removal by algal-bacterial reactors were not available.

Current knowledge on the impacts of SRT on the performance of algal-bacterial reactors is quite limited. And there is no clear direct proof showing that PAOs are abundant in a continuously illuminated algal-bacterial reactor. The aim of this study was to clarify the impacts of SRT on algal-bacterial reactors. The application of a membrane bioreactor provides an ideal condition for exact SRT control. Therefore, two photo bioreactors with dynamic filters were constructed. Two SRTs, i.e. 10 and 20 days, were applied.

2. Materials and methods

2.1. Reactor setup

The structure of the two-applied photo-bioreactors is shown in Fig. 1. Each reactor was made of a 2 L glass beaker. The effective volume of a reactor was 2 L. A dynamic filter made of denim fabric and support materials was applied in each reactor. The support materials consisted of two joints and the necessary wood bars between the two joints. The joints were constructed from polyvinyl chloride, and each had nine branches. The filter measured 15 cm × 7.5 cm. More details regarding the filter can refer to our previous works [22]. The size of the dynamic filter was 8 cm × 12 cm. The flux of the filter was 10 L/m^2.h. All the pumps were peristaltic pumps (Jihpump BT-100EA, Chongqing Jieheng Peristaltic Pumps Co., Ltd, China). A light source (YUN7-U, Shanghai Bolitong Lumination Co., Ltd, China) was applied. The light intensity on the surface of the light was 200 μmol/(m^2·s). The light source provided white light whose intensity decreased to 0 μmol/(m^2·s) within 3 cm. The reactor temperature was maintained at 25 °C by using water bath.

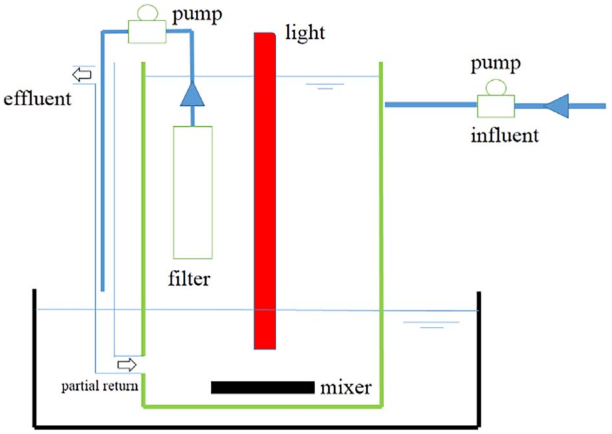

Fig. 1. Schematic view of the reactor.

The two reactors were applied with SRTs at 10 d (reactor A) and 20 d (reactor B), respectively. The hydraulic retention times for the two reactors were 8 h. The influent COD, ammonium, phosphate concentrations were 300 mg/L, 40 mg/L and 10 mg/L, respectively. This corresponded with the loads of 900 mg COD/L.d, 120 mg NH_4^+-N/L.d and 30 mg PO_4^{3-}-P/L.d. Detailed recipe of the applied wastewater is shown in table 1. The operation conditions for the two reactors are listed in table 2. In the stage 2, oxygen concentration was tried to be maintained at 0.1 mg/L by controlling air flow rate manually.

Activated sludge from a full scale domestic wastewater treatment plant (BeiBei wastewater treatment plant, Chongqing) was applied as inoculum. Meanwhile, algae collected at the wall of a secondary settler in the plant were also applied as inoculum. The initial sludge and algae concentrations in the reactor were 7.5 g/L and 7.5 g/L, respectively.

2.2. Routine analysis

COD, ammonium, nitrate, nitrite, phosphate, chlorophyll *a* (Chl a), total suspended solids (TSS) were measured following standard methods [23]. A pH meter was applied to measure pH in the reactor (SX 721. Sanxin Instrument, China). Dissolved oxygen concentration was measured (SG9, Mettler-Toledo International Inc. Co). Transmembrane pressure (TMP) was measured with a pressure transmitter (SD-800 V, Ning Hua Instrument, China, accuracy: 0.1%). Turbidity was measured using a portable turbidimeter (2100Q, HACH). A microscope (CX31RTSF, Olympus Corporation, Tokyo, Japan) was applied to observe the biomass in the reactors on the first day and the 150th day.

Table 1
Recipe of the synthetic wastewater.

Reagent	Substrate	Unit
CH_3COONa	384	mg/L
KH_2PO_4	47	mg/L
NH_4Cl	152.7	mg/L
Na_2HCO_3	300	mg/L
$MgSO_4·7H_2O$	75	mg/L
$CaCl_2·2H_2O$	36	mg/L
Ammonium ferric citrate	6	mg/L
$EDTANa_2$	1	mg/L
H_3BO_3	2.86	μg/L
$MnCl_2·4H_2O$	1.86	μg/L
$ZnSO_4·7H_2O$	0.22	μg/L
$Na_2MoO_4·2H_2O$	0.39	μg/L
$CuSO_4·5H_2O$	0.08	μg/L
$Co(NO_3)_2·6H_2O$	0.05	μg/L