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Effect of aeration rate on performance and stability of algal-bacterial symbiosis system to treat domestic wastewater in sequencing batch reactors

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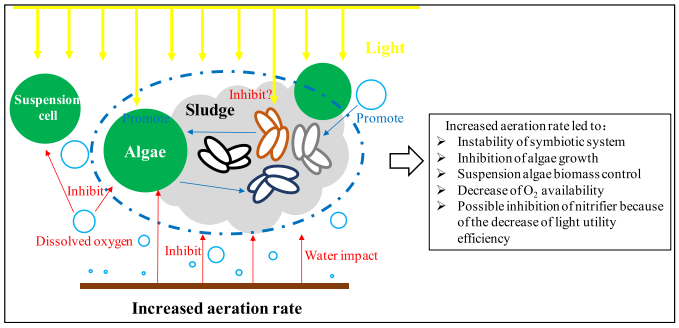
HIGHLIGHTS

- The role of DO on performance and stability of ABS system had been explored.
- The ABS system performed better for nutrients removal than CAS system.
- The interactions between algae and bacteria in ABS system had been identified.
- Algae could protect AOB and NOB from optical energy damage in ABS system.
- 0.2 L air/min aeration rate was optimal for formation of algal-bacterial symbiosis.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated aeration rate (0, 0.2, 0.4 and 1.0 L/min) effects on algal-bacterial symbiosis (ABS) and conventional activated sludge (CAS) systems while treating domestic wastewater in sequencing batch reactors. Experiment results showed that ABS system performed better on NH_4^+-N, total nitrogen and total phosphorus removal than CAS system, especially under lower aeration rate condition (0.2 L air/min), with removal efficiencies improvements of 18.90%, 12.45% and 46.66%, respectively. The mechanism study demonstrated that a favorable aeration rate reduction (half of traditional value in CAS system) could enhance algae growth but weaken hydraulic shear force, which contributed to the interactions between algae and sludge flocs and further stability of ABS system. In addition, algae growth protected both ammonia and nitrite oxidizing bacteria from optical damage. It is expected that the present study would provide some new insights into ABS system and be helpful for development of low-energy demand wastewater treatment process.

1. Introduction

Algal-bacterial symbiosis (ABS) system is known as a classic water self-purification process in natural water (Wang et al., 2008; Boelee et al., 2014). The CO_2 released by bacteria is consumed by algal photosynthesis (Muñoz and Guieysse, 2006) and then the O_2 released by algae is consumed by bacteria (Munoz et al., 2003). In this process, nutrients such as nitrogen (N) and phosphorus (P) are concomitantly eliminated by algal uptake (Van Den Hende et al., 2014; Zhang et al., 2011). Meanwhile, the ABS system can inhibit *E. coli* (Safonova and Reisser, 2005), recycle

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bio-energy (Wang et al., 2013) and enhance the carbon sequestration (Muñoz and Guieysse, 2006; Wang et al., 2014). Among them, the attractive potential of algae in nutrients (e.g., N and P) uptake from the polluted water has drawn considerable interest in the world (Christenson and Sims, 2011; Huang et al., 2015). And then the ABS system, as an emerging biotechnology, has been introduced into the exploration and development of wastewater treatment process.

Recently, more and more researchers have paid attention to investigate ABS system in the high rate algal ponds (HRAP) to achieve both biomass production and water purification. Medina and Neis (2007) studied the effect of food to microorganism (F/M) ratio and hydraulic retention time (HRT) on the stability of ABS system and obtained that the algal-bacterial system performed better at higher HRT (4.0 d) and lower F/M (0.15 kg BOD_5/kg MLSS·d). Similarly, a longer sludge retention time (SRT, 40 d) was more favorable for algal biomass harvesting while using pretreated wastewater as the substrate in the study of Valigore et al. (2012). And Su et al. (2012) cultivated low concentration sludge (about 60–600 mg/L) and algae in stirred photo-bioreactors without extra water exchange, and found that the algae to sludge inoculation ratios had a critical influences on nutrients removal. Through the above parameters adjustment, N and P removal efficiencies of ABS system could be up to 90% (Su et al., 2012). However, the operation conditions of ABS system for wastewater treatment process is similar to the water self-purification process, which is deviated from the demand of highly-efficiency wastewater treatment process. As well known, the ABS system performed not well on the removal rate of nutrients and a longer HRT (at least dozens of hours) was needed to achieve satisfactory performance during wastewater treatment (Posadas et al., 2015; Su et al., 2011), which might be attributed to slower autotrophs (i.e., microalgae) growth rate compared to the heterotrophs (i.e. bacteria etc.) (Amon and Benner, 1996; Lam et al., 2008). Until now, few studies have focused on the ABS system to explore and develop high-efficiency wastewater treatment technology. Van Den Hende et al. (2011) found that increased inorganic carbon/organic carbon ratio could enhance algae growth rate and external magnetic field effects could stimulate both algal growth and O_2 production (Hao et al., 2015). Moreover, Li et al. (2015) found that TiO_2 nanoparticles could enhance the granulation process by forming stable algal-bacterial granules. And Huang et al. (2015) investigated the effect of algae growth on aerobic granular sludge (AGS) at a very short HRT (8 h) recently. The above studies provided possible application of microalgae in the field of highly-efficient wastewater treatment process. It's of great concern to improve algal growth rate and study how the symbiotic effect of microalgae and bacteria formed in the ABS system.

Dissolved oxygen (DO) is a critical factor to the conventional aerobic biological wastewater treatment process, which can be adjusted by controlling aeration rate (with other parameter unaltered). Bacteria-based active sludge grows well in aerobic conditions, and DO often ranges from 2 to 4 mg/L (Grady et al., 2011). DO content above this range not only increases energy consumption but also may lead to sludge bulking, and DO content below this range may result in incomplete degradation of organic compounds (Ekama and Wentzel, 1999). What's more, the growth of microalgae community is limited by DO (Mclean et al., 2000). The algae use light and carbon dioxide (CO_2) in the water to produce oxygen by photosynthesis, DO in water would limit its photosynthetic rate and then reduce the growth rate of algae (Posadas et al., 2015). The variation of DO in water may also affect the balance between bacteria-based activated sludge and microalgae community. Thus, it's necessary to investigate the influence of DO (aeration rate) on the performance and stability of ABS system.

The main objective of this work was to study the feasibility of algae added into the conventional sequencing batch reactors (SBRs) for enhancing chemical oxygen demand (COD) and nutrients removal from domestic wastewater, and explore the effects of aeration rate on performance and stability of the proposed ABS system. The mechanisms for enhancing COD and nutrients removal from wastewater were investigated by analyzing the microbial activity. And the stability of ABS system was evaluated by algal growth and sludge flocs size distribution. It is expected that this work would not only provide some new insights into the role of DO in ABS system but also be meaningful for the exploration of ABS system for highly-efficient wastewater treatment technique.

2. Materials and methods

2.1. Experiments set-up and operation

The laboratory-scale experiments were conducted in 8 SBRs, which were made of glass (25 cm in depth and 16 cm in diameter), at room temperature (25 ± 2 °C). The working volume was 3 L. These 8 reactors were equally divided into two groups, which were set up to study the effects of DO on the performance of the ABS system and the corresponding mechanism. One was operated with the conventional activated sludge (CAS) process, which was named R_C group, and inoculated with only sludge inoculum. The other was operated with ABS process, which was named R_S group, and inoculated with the mixture of sludge and algal inoculum. The SBRs were applied to treat synthetic domestic wastewater and operated sequentially with a 12-h cycle: 1 h for fill, 9 h for aeration, 1 h for settling, and 1 h for withdraw. The volumetric exchange ratio was kept at 80%, leading to a HRT of 15 h. The SRT of all SBRs were 20 d. The operation time were 35 days, and the first 5 days were the domestication stage. The initial mixed liquor suspended solids (MLSS) concentration was 1500 mg/L in each reactor and the algae to sludge ratio of R_S group was 1:3 (w/w). The R_C group was operated in dark environment (i.e., the SBRs in R_C group were covered with silver paper), and the R_S group was irradiated 18 h per day (from 5:00 to 23:00) by four independent strip lights (50 cm) surrounding the SBRs instead of sunlight. The light intensity was approximately 6000 lx in the inner wall of reactors.

In order to investigate the effect of different aeration rates on the performance and stability of the ABS system while treating domestic wastewater, the R_{S1}, R_{S2}, R_{S3} and R_{S4} in R_S group were pumped in air with different aeration rate: 0, 0.2, 0.4 and 1.0 L/min, respectively, and the aeration rate supply in R_C group was same to R_S group. The average DO and pH value of each reactor during the whole operation period were shown in Table 1. The magnetic stirrers were used to improve O_2 transformation and keep a homogeneous system.

2.2. Synthetic wastewater and cultivation of sludge and microalgae

The synthetic ingredients of simulated domestic wastewater were listed as follows (mg/L): glucose 150, starch 150, NH_4Cl 151, KH_2PO_4 47, $NaHCO_3$ 300, $MgSO_4{\cdot}7H_2O$ 50, $CaCl_2$ 5. The trace elements were also added into synthetic wastewater (mg/L): H_3BO_3 2.86, $MnCl_2{\cdot}4H2O$ 1.86, $ZnSO_4{\cdot}7H_2O$ 0.22, $Na_2MoO_4{\cdot}2H_2O$ 0.39, $CuSO_4{\cdot}5H_2O$ 0.08, and $Co(NO_3)_2{\cdot}6H_2O$ 0.05. And the theoretical concentrations of COD, total N (TN) and total P (TP) of influent were 300, 40 and 10 mg/L, respectively.

The aerobic inoculation sludge (without algae) was obtained from the secondary sedimentation tank of Taiping wastewater treatment plant (WWTP, Harbin, China). After a week's acclimation, the initial MLSS of seed sludge was adjusted to1500 mg/L.