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Short Communication

High-Rate Algae Pond Coupled with Polyester Fiber Strips for Organics and Nutrient Removal in a Cold Climate

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Abstract

Algae growth and photosynthesis can be inhibited in high-rate algae ponds (HRAP) in cold climates. This study evaluated the feasibility and importance of polyester fiber strips (PFS) that can be applied to HRAP as growing sites for algae survival, thus enhancing HRAP performance. The results indicated that 42.0±2.0% TN, 86.0±1.0% TP and 99.0±1.0% DCOD were reduced in HRAP with high PFS amounts, which outperformed HRAP with low PFS amounts and was significantly higher than control. The positive role of PFS on algae biomass production could effectively remove organics and nutrient from wastewater.

Keywords: high-rate algae pond, polyester fiber strip, cold climate, organics and nutrient removal

Introduction

Algae can help remove organics and nutrient (N, P) from wastewater [1-2]. High-rate algae ponds (HRAP) are an efficient and inexpensive technology for algae biomass production, and in which a large quantity of wastewater can be treated [3]. Algae growth is considerably influenced by climatic conditions, particularly temperature [4-5]. Low temperature restrains algae photosynthetic activities and reduces algae growth, resulting in low purification efficiency. The main objective of HRAP is to prevent algae loss for efficient removal of multi-pollutants. However, slow growth and survival rate under cold climate usually causes algae loss, thus affecting HRAP performance [6]. An important aspect in improving HRAP performance is finding a cost-effective and sustainable method for increasing algae biomass.

It is well known that polyester fiber has excellent biocompatibility and bio-binding capacities [7]. Polyester-fiber strips (PFS) slung up in HRAP can provide void spaces and growing sites for algae growth and survival under cold conditions; in addition, PFS also provide large interfaces for supporting biological and biochemical reaction to clean up the wastewater. Due to structural properties, PFS might improve HRAP performance under cold climate, which has not been investigated to date.

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The objective of this study was to identify the role and amount of PFS on algae biomass and pollutant removal in HRAP. The results of this study were conducive to enhancing our understanding of HRAP design and treatment performance in cold climates, and it might provide significant implications for effective operation of HRAP in cold climates.

Material and Methods

PFS were slung up into a lab-scale HRAP via transparent polycarbonate pipes (Fig. 1). The dimension of each strip is 60 cm in length, 6 cm in width and 2 cm in thickness. PFS were fed with the algae (*Microcystis aeruginosa*) solution in a glass container of 10 L volume for 72 h, prior to being hung up in HRAP. The algae were cultured and enriched in an artificial climatic chamber with BG culture medium and tap water [8]. The strengthened PFS was packed with algae.

Three lab-scale HRAP systems (namely A, B and C) were constructed with identical dimensions (length: 0.96 m, width: 0.60 m, height: 0.60 m) on the campus of Donghua University, located in Shanghai, China (38°39′27″N, 104°04′58″E). Useful volume of each system was 0.32 m^3. A mechanical stirrer was used in each system to mix the wastewater at an average surface velocity of 0.15±0.03 $m\ s^{-1}$. The algae used in HRAP were *Microcystis aeruginosa* and chlorophyll a (Chl-a), and contents were determined as an indicator of algae biomass. The experiments were conducted during the winter (October to February) and operated intermittently with hydraulic retention time (HRT) of 3 d. The climate is classified as monsoon subtropical with cold winters (2 to 15ºC).

Three systems were operated under different conditions. PFS hung vertically onto polycarbonate pipes were not emplaced in system A (control), while they were installed at the top of systems B and C. Three polycarbonate pipes were used in system B, while six polycarbonate pipes were used in system C. Each polycarbonate pipe was draped with three PFS. Each system received synthetic wastewater from influent tanks (300 L) via peristaltic pumps at a stable inflow rate of 4.0±0.2 $L\ min^{-1}$. The total inflow was 250 L within 1 h. The parameters of synthetic wastewater were set as follows: ammonia nitrogen (NH_4-N), 23.8±1.0 $mg\ L^{-1}$; total nitrogen (TN), 25.0±1.2 $mg\ L^{-1}$; dissolved reactive phosphorus (DRP), 5.22±0.5 $mg\ L^{-1}$; total phosphorus (TP), 5.58±0.5 $mg\ L^{-1}$; dissolved chemical oxygen demand (DCOD), 70.0±5.0 $mg\ L^{-1}$; and dissolved oxygen (DO), 4.5±0.3 $mg\ L^{-1}$; pH, 7.5±0.2; Chl-a, 20.0±5.0 $mg\ L^{-1}$.

Influent water samples were collected when synthetic wastewater was prepared. Effluent water samples were collected at 6 h, 12 h, 24 h, 30 h, 36 h, 48 h, 54 h, 60 h, and 72 h to evaluate the variations of Chl-a, pH, DO and pollutant removal of the three systems. Water temperature, DO, pH, and Chl-a were immediately measured *in situ* after using a portable water quality multi-probe (Manta 2, EURERA, USA). For NH_4-N, TN, DRP, TP, and DCOD determination with the multi-parameter colorimeter (DR900, HACH, USA), the samples were filtered through Whatman GF/C glass-fiber filters (0.22 μm) for analysis.

All the experiments were performed in triplicate. Statistical functions of Origin 8.0 software (OriginLab, MA, USA) were used to analyze the measurement data. Statistical analyses were performed by Student's *t* test at $p<0.01$.

Results and Discussion

Fig. 2 shows the profiles of Chl-a, DO and pH in HRAP. As observed in Fig. 2a), Chl-a content in PFS systems (B and C) increased more significantly than in system A (control). The fact that highest Chl-a content of system B (350 $mg\ L^{-1}$) was 78% more than that of system A (197 $mg\ L^{-1}$), which indicated that PFS promoted algae growth. In addition, significant differences in Chl-a profile between systems B and

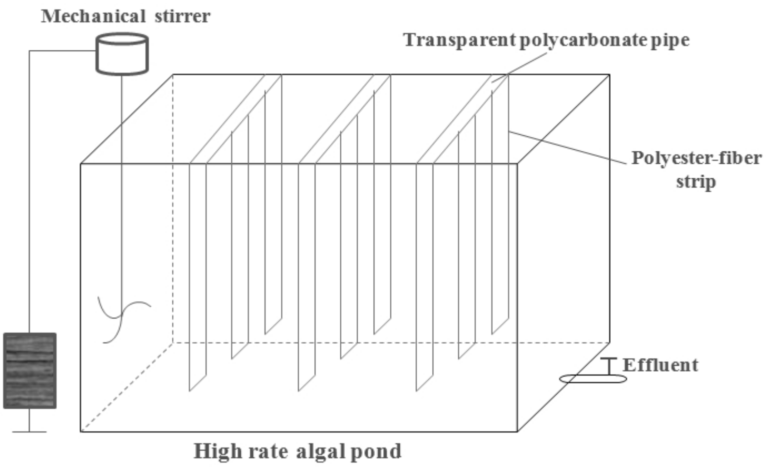

Fig. 1. Schematic diagram of experimental HRAP.

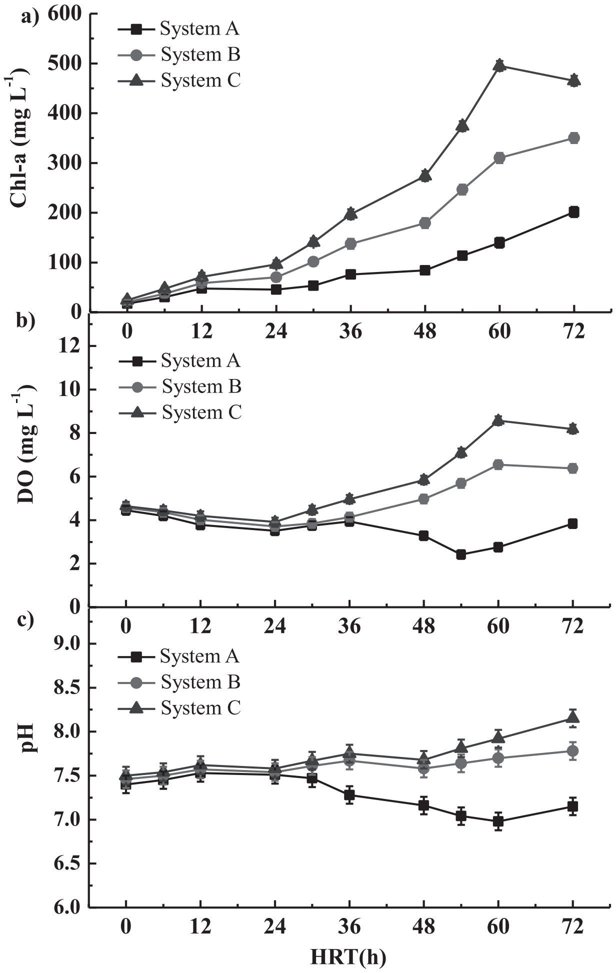

Fig. 2. Profiles of Chl-a a), DO b), and pH c) in HRAP.

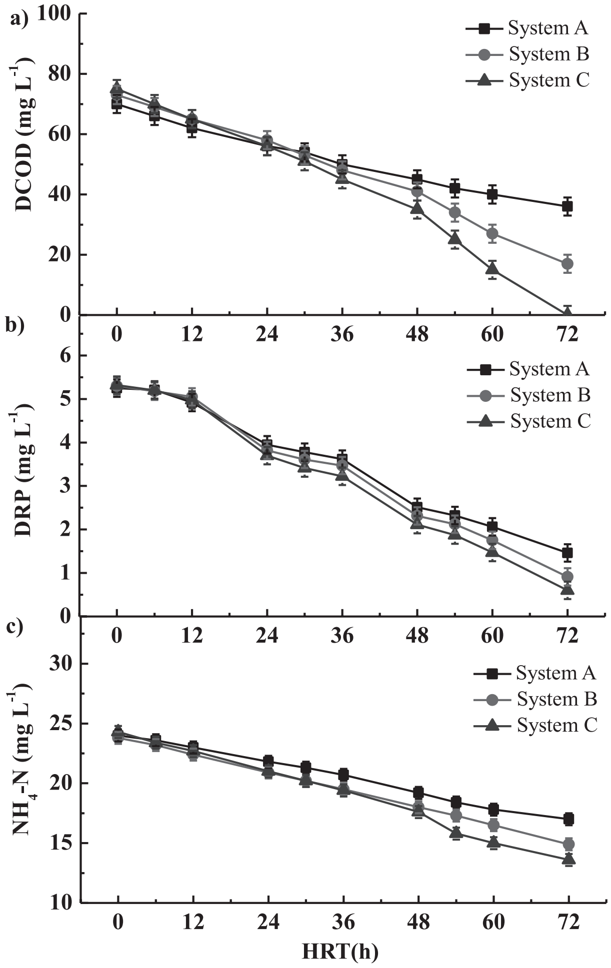

Fig. 3. Profiles of DCOD a), DRP b), and NH_4-N c) in HRAP.

C were observed ($p<0.01$). The algae biomass was higher in system C compared with system B due to the differences in PFS amount. The increasing of PFS amount in HRAP accelerated algae growth.

Algae photosynthesis produces high levels of DO and pH, which fluctuate diurnally [9]. According to Fig. 2b), DO content decreased substantially at the initial stage due to the requirement of aerobic heterotrophic metabolism. The highest DO content reached 6.55 and 8.57 mg L^{-1} in PFS systems B and C compared to 3.84 mg L^{-1} in system A. As shown in Fig. 2c), photosynthesis increases the pH via consumption of CO_2 and HCO_3^- [10]. The pH profile in PFS systems B and C increased substantially, which profited from the growing algae via PFS. In contrast, the pH range of system A (6.98-7.53) was lower than that of system B (7.46-7.78) and system C (7.50-8.15). PFS contributed to algae growth, thus facilitating the increase of DO and pH in HRAP. With the increasing PFS amount, the growing algae facilitated photosynthesis and higher DO content and pH value was obtained.

Fig. 3 shows the profiles of DCOD, DRP, and NH_4-N in HRAP. DCOD value gradually decreased with HRT in three systems (Fig. 3a). Pollutant removal performance of the three systems was presented in Table 1. As presented in Table 1, PFS systems B and C (76.7% and 99.0%) had the capacity to remove DCOD more efficiently than system A (48.6%), which was ascribed to aerobic degradation of DCOD via algal photosynthesis aeration. The increasing PFS amount contributed to further improvement of DCOD reduction. Consequently, DCOD removal in system C was significantly higher than that of system B ($p<0.01$).

Ammonia and phosphate may be nutrient sources for algae [11]. Phosphorus removal was improved by algae-induced chemical precipitation and assimilation [12]. DRP value gradually decreased in three systems (Fig. 3b). PFS systems B and C showed better DRP removal performances of 82.8% and 88.5% (Table 1), which indicated that PFS were conductive to phosphorus assimilation by facilitating algae biomass. Additionally, chemical precipitation of phosphorus contributed to DRP elimination due to the elevated pH in PFS systems B and C. With the increasing PFS amount, system C exhibited higher DRP removal than system B. The main component of TP in the influent was DRP, hence the tendency of TP removal was consistent with the DRP profile in three systems. The highest TP elimination was observed in system C.

Table 1. Pollutant removal performance of the three systems.

Parameter	Influent (mg L^{-1})	System	Effluent (mg L^{-1})	Removal (%)
NH_4-N	23.8±1.0	A	17.0±0.5	29.2±2.0
		B	14.9±0.5	37.4±2.0
		C	13.6±0.5	44.0±2.0
TN	25.0±1.2	A	18.4±0.8	27.0±2.0
		B	16.1±0.8	36.9±2.0
		C	14.5±0.8	42.3±2.0
DRP	5.22±0.5	A	1.46±0.2	72.1±1.0
		B	0.91±0.2	82.8±1.0
		C	0.60±0.2	88.5±1.0
TP	5.58±0.5	A	1.63±0.2	70.8±1.0
		B	1.13±0.2	80.4±1.0
		C	0.78±0.2	86.1±1.0
DCOD	70.0±5.0	A	36.0±3.0	48.6±3.0
		B	17.0±3.0	76.7±3.0
		C	1.0±1.0	99.0±1.0

Algal assimilation represents the direct nitrogen removal mechanism while ammonia volatilization causes indirect nitrogen removal [13]. Higher retention time enhanced NH_4-N removals (Fig. 3c). PFS systems B and C were significantly more effective in NH_4-N removal than system A ($p<0.01$), which could be attributed to the algae growing more actively in HRAP with PFS. Furthermore, ammonia volatilization contributed to NH_4-N elimination due to the elevated pH in PFS systems B and C. With the increasing PFS amount, reduction in NH_4-N was more significant in system C, where the algae were most abundant ($p<0.01$). The tendency of TN removal was in accordance with the drop of NH_4-N. The highest TN elimination was also observed in system C.

Conclusions

PFS provided growing sites and large interfaces conducive to algae growth and the occurrence of biochemical reaction, which improved algae biomass and pollutant removal performance of HRAP systems under cold climate. Better removal performance was obtained in PFS systems for algae flourishing growth. The increasing PFS amount in HRAP efficiently promoted the removal of organics and nutrients. This study demonstrated the application prospect of cost-effective PFS for algae growth, which gave an effective solution for the dilemma of low algae biomass in HRAP in a cold climate.

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Conflict of Interest

The authors have not declared any conflict of interest.

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