Chemical Engineering Journal 335 (2018) 154–160

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Potential of wastewater treatment using a concentrated and suspended algal-bacterial consortium in a photo membrane bioreactor

Jixiang Yang[a,*], Yao Gou[b], Fang Fang[b], Jinsong Guo[b], Lunhui Lu[a], Yuemin Zhou[a], Hua Ma[b]

[a] Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing, China
[b] School of Urban Construction and Environmental Engineering, Chongqing University, Chongqing, China

ARTICLE INFO

Keywords:
Algae
Membrane bioreactor
Photo
Wastewater
Algal-bacterial

ABSTRACT

Current algal-bacterial consortia require hydraulic retention times (HRTs) of up to 2–10 days for wastewater treatment. The application of a photo membrane bioreactor (PMBR) culturing an algal-bacterial consortium should significantly reduce the HRTs, which has not been attempted before. A low light intensity, 200 μmol/(m^2·s), was applied in a PMBR. The results showed that ammonium was almost completely removed and the removal efficiency of chemical oxygen demand was 90% when the HRT was as low as 24 h and mechanical aeration was not applied. Ammonium-oxidizing bacteria and algae approximately equally shared the ammonium in the reactor. Phosphate reduction was approximately 3 mg PO_4^{3-}-P/L.h. A light intensity of up to 600 μmol/(m^2·s) did not inhibit algal activity. The complete removal of ammonium resulted in a decline in the chlorophyll *a* concentration. Nevertheless, the reactor performance remained stable. Heterotrophic bacteria, autotrophs, algae and phosphate-accumulating organisms coexisted and functioned in the reactor. Furthermore, a sustainable flux of 15 L/m^2.h enabled operating the filter of the PMBR at a transmembrane pressure as low as 4 kPa. Considering the stable pollutant removal performance and significant reduction in HRT, this PMBR has the potential to be applied in wastewater treatment.

1. Introduction

Since biological wastewater treatment using activated sludge is energy intensive, algal–bacterial consortia can be an alternative method of treatment. The aeration cost can account for up to 60% of the total operation cost of a conventional wastewater treatment plant, but algae can produce sufficient oxygen that can sustain the growth of bacteria and adsorb ammonium and phosphate [1]. Bacteria can provide algae with carbon dioxide. Applying algae and bacteria can generally achieve better bioreactor performance than applying bacteria alone [2].

Algae and bacteria are applied to treat domestic wastewater, and 2–10 days are generally required for pollutant removal [3-11]. The high hydraulic retention times (HRTs) result in high energy costs, which may result from the low suspended biomass concentrations in reactors. However, high footprints restrict the application of low rate technologies for wastewater treatment [12]. In addition, algal–bacterial biofilm bioreactors usually require high HRTs, thus indicating that algal–bacterial biofilm bioreactors should be further improved [13,14].

Membrane bioreactors are extensively applied to retain activated sludge and usually require small energy footprints [15]. Limited available reports show that the algae concentration in an algal photo membrane bioreactor (PMBR) is significantly higher than that in a bioreactor without a membrane [16,17]. Similar to conventional biological membrane bioreactors, the benefits of applying a PMBR to algal cultures include avoiding a wash out of micro-algal cells and enhancing the micro-algal cell retention time in the bioreactor. Thus, the algal cell concentration can be controlled in a photobioreactor with a membrane unit [18]. The application of a PMBR provides great freedom in selecting the optimum biomass concentration for optimizing the efficiency of the bioreactor. PMBRs have been used to treat wastewater by applying phototrophic biomass, such as algae and purple phototrophic bacteria [12,19]. In addition, a sequential batch reactor, in which activated sludge is applied, is a widely applied technology for wastewater treatment. However, as it is difficult to separate algae from water, and a high level of suspended solids is expected in the effluent of algal-bacterial photosequencing batch reactors that still require large environmental footprints [20,21]. A reactor with a low-cost filter could be a potential alternative to the algal-bacterial photosequencing batch reactor. To the authors' knowledge, no research has yet applied an algal–bacterial consortium in a PMBR for treating domestic wastewater.

* Corresponding author.
E-mail addresses: jixiang.yang@cigit.ac.cn (J. Yang), gouyao@cqu.edu.cn (Y. Gou), fangfangcq@cqu.edu.cn (F. Fang), guojs@cigit.ac.cn (J. Guo), lulunhui@cigit.ac.cn (L. Lu), zhouyuemin@cigit.ac.cn (Y. Zhou), huama@cqu.edu.cn (H. Ma).

http://dx.doi.org/10.1016/j.cej.2017.10.149
Received 7 September 2017; Received in revised form 23 October 2017; Accepted 25 October 2017

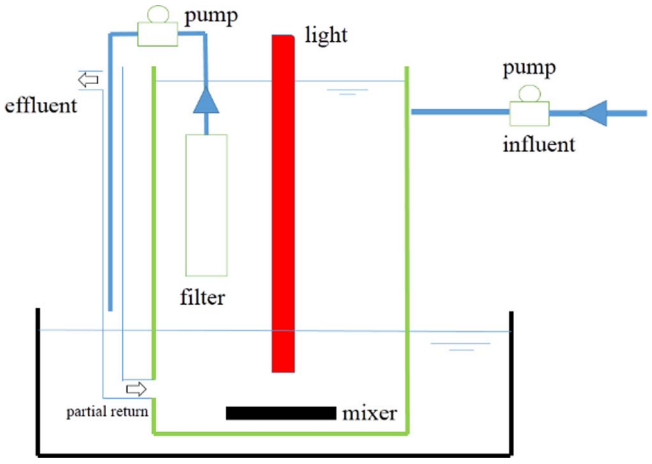

Fig. 1. Schematic view of the photobioreactor with dynamic filtration.

Therefore, the potential of applying this type of novel bioreactor for wastewater treatment remains unclear.

This aim of this study was to investigate whether an algal–bacterial PMBR could efficiently clean wastewater and thereby reduce the high HRTs. Experiments were performed to determine whether heterotrophic bacteria, autotrophs, phosphate-accumulating organisms (PAOs), and algae coexisted and how active they were in the reactor.

2. Materials and methods

2.1. Continuous reactor operation

The applied photobioreactor is shown in Fig. 1. The reactor was made of a 2 L glass beaker. The effective volume of the reactor was 2 L. A dynamic filter made of denim fabric and support materials was applied in this study and was also applied in one of our previous works [22]. The size of the dynamic filter was 8 cm × 12 cm. The flux of the filter was 15 L/m^2.h. All the pumps were peristaltic pumps (Jihpump BT-100EA, Chongqing Jieheng Peristaltic Pumps Co., Ltd., China). Influent and effluent were continually provided by the peristaltic pumps. The applied flux resulted in a difference between influent flow and effluent flow. To maintain the liquid volume in the reactor, partial effluent return was applied, as was done in our previous work [22]. This method allows for different filter fluxes to be applied, and the liquid level in the reactor was always constant.

Light (YUN7-U, Shanghai Bolitong Lumination Co., Ltd., China) was applied to the algal–bacterial consortium. The light intensity on the surface of the light was 200 μmol/(m^2·s). A magnetic mixer was applied to mix the liquid in the reactor. The reactor did not have a cover, and thus the liquid in the reactor contacted the air. However, the oxygen supplied through air diffusion could be disregarded compared with the oxygen supplied by the algae [1]. The room temperature was set to 22 °C. Given the application of light and the water bath, the temperature of the algal–bacterial consortium was 28 °C.

The HRT of the reactor was 24 h. A partial permeate return was applied to solve the difference between influent flow and the effluent, as was previously applied [22]. The biomass left the reactor only when the total suspended solid (TSS) concentration measurements were performed. The volume of each sample taken from the reactor was 5 ml for each TSS measurement.

Synthetic wastewater was prepared from sodium acetate, which represents biodegradable organic pollutants [1]. The total chemical oxygen demand (COD) concentration of the wastewater was 300 mg l^{-1}, which corresponded to a volumetric load of 0.3 g COD (l d)$^{-1}$. The composition of the synthetic wastewater is presented in Table 1.

The pH of the substrate was 7.5. It was reduced to 7 using HCl after the 21st day to control the pH in the reactor. $NaNO_3$, K_2HPO_4, Na_2CO_3, and citric acid were applied to promote algal growth. These chemicals were not added after the 24th day.

Table 1
Components of the substrates.

Reagent	Substrate 1	Substrate 2	Unit
CH_3COONa	384.6	384.6	mg/L
KH_2PO_4	47	47	mg/L
NH_4Cl	152.7	152.7	mg/L
Na_2HCO_3	300	300	mg/L
$NaNO_3$	1500	Not applied	mg/L
$K_2HPO_4{\cdot}3H_2O$	40	Not applied	mg/L
Citric Acid	6	Not applied	mg/L
Na_2CO_3	20	Not applied	mg/L
$MgSO_4{\cdot}7H_2O$	75	75	mg/L
$CaCl_2{\cdot}2H_2O$	36	36	mg/L
Ammonium ferric citrate	6	6	mg/L
$EDTANa_2$	1	1	mg/L
H_3BO_3	2.86	2.86	μg/L
$MnCl_2{\cdot}4H_2O$	1.86	1.86	μg/L
$ZnSO_4{\cdot}7H_2O$	0.22	0.22	μg/L
$Na_2MoO_4{\cdot}2H_2O$	0.39	0.39	μg/L
$CuSO_4{\cdot}5H_2O$	0.08	0.08	μg/L
$Co(NO_3)_2{\cdot}6H_2O$	0.05	0.05	μg/L

Activated sludge from a full-scale domestic wastewater treatment plant (BeiBei wastewater treatment plant, Chongqing) was used as the inoculum. Algae collected at the wall of a secondary settler in the plant were also used as an inoculum. The initial sludge and algae concentrations in the reactor were 900 mg/L and 900 mg/L, respectively.

2.2. Routine measurements

COD, ammonium, nitrate, nitrite, phosphate, and chlorophyll *a* concentrations were measured following standard methods [23]. A pH metre was used to measure the pH in the reactor (SX 721, Sanxin Instruments, China). The dissolved oxygen concentration was measured (SG9, Mettler-Toledo International Inc. Co). Transmembrane pressure (TMP) was measured with a pressure transmitter (SD-800V, Ning Hua Instrument, China; accuracy: 0.1%). Turbidity was measured using a portable turbidimeter (2100Q, HACH). A microscope (CX31RTSF, Olympus Corporation, Tokyo, Japan) was used to observe the biomass in the PMBR.

2.3. Light curve measurement

A PhytoPAM instrument (Zealquest Scientific Technology Co., Ltd., China) was used to analyse the algal activity [24]. The machine uses light with four different wavelengths, namely, 470, 520, 645, and 665 nm, to distinguish cyanobacteria, green algae, and diatoms. When light with a certain wavelength is applied, a light curve can be obtained by varying the quantum light density and measuring the corresponding electronic transfer rate. The electronic transfer rate increases linearly with the increase in the quantum light density when the quantum light density is low. Then, the electronic transfer rate increases and becomes almost constant in a certain value (maximum electronic transfer rate, ETR_{max}) as the quantum light density increases further.

When the electronic transfer rate increases linearly with the increase in the quantum light density, the slope of the light curve is called alpha. Alpha is a parameter that measures the capacity of algae to utilize light. When the electronic transfer rate is half of the ETR_{max}, the corresponding quantum light density is called Ik.

All data regarding light curves were provided with PhytoPAM directly.