Ecotoxicology and Environmental Safety 152 (2018) 1–7

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

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

Evaluation of kenaf fibers as moving bed biofilm carriers in algal membrane photobioreactor

Zahra Derakhshan[a,b,c], Amir Hossein Mahvi[d,e], Mohammad Hassan Ehrampoush[a], Mohammad Taghi Ghaneian[a], Saeed Yousefinejad[f], Mohammad Faramarzian[g], Seyed Mohammad Mazloomi[h], Mansooreh Dehghani[g,*], Hossein Fallahzadeh[i]

[a] *Environmental Science and Technology Research Center, Department of Environmental Health Engineering, Shahid Sadoughi University of Medical Sciences, Yazd, Iran*
[b] *Student Research Committee, Shahid Sadoughi University of Medical Sciences, Yazd, Iran*
[c] *Department of Environmental Health, School of Health, Larestan University of Medical Sciences, Larestan, Iran*
[d] *Center for Solid Waste Research (CSWR), Institute for Environmental Research (IER), Tehran University of Medical Sciences, Tehran, Iran*
[e] *Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran*
[f] *Research Center for Health Sciences, Department of Occupational Health Engineering, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran*
[g] *Research Center for Health Sciences, Department of Environmental Health, School of Health, Shiraz University of Medical Sciences, Shiraz, Iran*
[h] *Nutrition Research Center, Department of Food Hygiene and Quality Control, School of Nutrition and Food Sciences, Shiraz University of Medical Sciences, Shiraz, Iran*
[i] *Prevention and Epidemiology of Non-Communicable Disease Research Center, Shahid Sadoughi University of Medical Sciences, Yazd, Iran*

A R T I C L E I N F O

Keywords:
Algal biofilm
Biofilm carriers
Hybrid membrane photobioreactor
Microalgae
Sludge yield
Wastewater treatment

A B S T R A C T

In this lab-scale study, the feasibility of using kenaf fibers as moving bed biofilm carriers in hybrid microalgal membrane photobioreactors (HMPBR) in organic matter and atrazine elimination from real secondary effluent was evaluated. For evaluating the kinetics of biofilm substrate consumption, an experimental model was proposed. Inoculation of wastewater samples with free carriers resulted in the greater removal of target pollutants. Removal efficiency of atrazine and chemical oxygen demand (COD) increased to 27% and 16%, with respect to the control, respectively. The total biomass accumulation in HMPBR exceeded 5 g/L, and the microalgae tended to aggregate and attached to biofilm carriers. The removal efficiency of HMPBR improved significantly via inoculation of kenaf fiber carriers with bioremediation microalgal strains ($p < 0.01$). A lower stabilization ratio (VSS/TSS) was also recorded. The biomass in HMPBR included more lipids and carbohydrates. The results revealed that kenaf fibers could improve and upgrade the biological activity of different wastewater treatment applications, considering the great potential of biofilm carriers and their effluent quality.

1. Introduction

The increase in population has resulted in production of a large amount of wastewater and the release of uncontrolled pollutants into the environment leading to a gradual decline in the quality of water resources. In this regard, the growing social concerns for conservation of natural water resources have led to development of strict rules regarding the necessary treatment before discharging of wastewater in the environment and the development of various types of treatment methods (Derakhshan et al., 2017a, 2017b; Kumar et al., 2015). Among different recent approaches, microalgal membrane photobioreactor (MPBR) has been successfully applied in wastewater treatment. Microalgae have been used in large ponds for the treatment of wastewater since long ago. (Luo et al., 2017; Praveen and Loh, 2016a; Torres et al., 2017). One of the most important limitations of microalgae systems application during the treatment processes is recovery and separation of microalgae from treated effluent streams. Among the solutions to deal with this problem, the technique of microalgae immobilization has been predominantly considered. One of the benefits of this method is providing a suitable medium for maintenance of active cells in the treatment process, which in turn leads to an increase in cell retention time within the bioreactor (Luo et al., 2017; Novoveská et al., 2016). Algal biomass accumulated in photobioreactors can also be used for producing methane, compost, animal feed, and liquid biofuels. In

Abbreviations: ATZ, Atrazine; COD, Chemical Oxygen Demand; DO, Dissolved Oxygen; EPS, Extracellular Polymeric Substances; HMPBR, Hybrid Microalgal Membrane Photobioreactor; HRT, Hydraulic Retention Time; MLSS, Mixed Liquor Suspended Solids; OLRs, Organic Loading Rates; MPBR, Membrane Photobioreactor; SRT, Solids Retention Time; TSS, Total Suspended Solids; VSS, Volatile Suspended Solids; VOL, Volumetric Organic Loads; VOR, Volumetric Organic Removal; OD, Optical Density

* Corresponding author.
E-mail address: mdehghany@sums.ac.ir (M. Dehghani).

https://doi.org/10.1016/j.ecoenv.2018.01.024
Received 7 November 2017; Received in revised form 9 January 2018; Accepted 11 January 2018

Nomenclature

B_{ATZ}	Volumetric atrazine loading (g_{ATZ}/Ld).
C_e	Atrazine concentrations in the effluent (g/L).
C_i	Atrazine concentrations in the influent (g/L).
HRT	Hydraulic retention time (day or hour).
K	Half saturation constant (g_{ATZ}/Ld).
Q	Inflow rate (L/d).
r_{ATZ}	Volumetric atrazine removal (g_{ATZ}/Ld).
r_{max}	Maximum substrate removal rate (g_{ATZ}/Ld).
S	Effluent substrate concentration (g/L).
S_0	Influent substrate concentration (g/L).
V	Reactor volume (L).

these systems, discharge of the evacuated effluent into the environment is expected, without separation of microalgae from the aqueous environment. Since microalgal-based wastewater treatment systems require extensive land and space, efforts have been taken to advance these systems by resorting to ultra-compact systems (Boonchai and Seo, 2015; Praveen and Loh, 2016b; Thomas et al., 2015). The biofilm systems and increase in microalgae attached growth enable them to keep biomass in abundance during short periods of hydraulic retention times (HRTs). Since mixing is not required during these processes, energy consumption and costs are going to be reduced (Luo et al., 2017). Biological wastewater treatment is usually performed by aerobic and anaerobic processes as their discharged effluent still contains inorganic compounds, such as nitrate, ammonium, and phosphate ions that can contaminate water resources. This causes algal blooming, non-ionized ammonia toxicity for fish and other aquatic organisms, and an interference with the disinfection process when free residual chlorine is needed (Grady Jr et al., 2011; Kesaano and Sims, 2014). Based on previous studies, P and N are key factors causing occurrence of eutrophication, therefore, further treatment would be necessary to prevent this incidence in aquatic environments (Conley et al., 2009). Since microalgae are able to absorb phosphorus and nitrogen in very low concentrations, they have this potential to regenerate phosphorus and nitrogen. For this reason, it is one of the most suitable and sustainable alternatives to post-treatment systems (Kesaano and Sims, 2014; Novoveská et al., 2016). Several materials have been tested as carriers in photobioreactor (Zhang et al., 2017). It is believed that cultivation and biomass production in algal biofilm systems depend on algal strains and environmental conditions, as well as the features of materials used as media for attached growth. It should be noted that materials for algal cell attachment should be durable, inexpensive, accessible, and non-toxic to algal cells, and so on. It is advisable that materials which have the ability to produce biofilms are used (Luo et al., 2017; Zhang et al., 2017). A summary of the performance of the algal photobioreactors, found in the previous literature and this study, is presented in Table 1S in the Supplementary data. As it can be seen from the Table 1S, most materials used as carriers were either costly (e.g., membrane and glass filtration fabric) or had major construction costs (e.g., metal meshes). Moreover, most of these materials were not disposable or durable; therefore, they were unsuitable for full-scale application. Therefore, we aimed to develop a novel biofilm technology with kenaf fibers as biofilm carriers, which are both environmentally friendly and cost-effective with a global distribution (Gao et al., 2015; Kesaano and Sims, 2014; Zhang et al., 2017). Therefore, this study aimed to develop a novel biofilm technology with kenaf fibers as biofilm carriers, which are both environmentally friendly and cost-effective with a global distribution. Kenaf, with a high annual production rate, is able to act as a natural carrier for algal cell attachment and promote the formation of algal biofilms in attached growth systems. Following cultivation, algal biomass is harvested with kenaf via scrapping. The harvested blend (containing algal biomass and kenaf) can be applied directly for bioenergy conversion as a feedstock (Akil et al., 2011; Nishino et al., 2003).

The aim of the present study was to explore the feasibility of kenaf fibers as biofilm carriers in hybrid microalgal membrane photobioreactor in elimination of xenobiotics from wastewater. We concentrated on the removal of COD and atrazine (as a model of chlorinated herbicide compounds widely used in agriculture) from aquatic environments. Furthermore, special attention has been paid to the capacity of such system for the aforementioned parameters and the involved factors in its application in different operational conditions have been explored. Attempts were taken in order to obtain the final effluent concentration.

2. Material and methods

2.1. Preparing and start-up of the photobioreactor

Two reactors, MPBR and control (the reactor without carriers was blank control), were used for parallel operation under the same conditions in order to determine the effectiveness of kenaf fibers as biofilm carriers for biological removal of target pollutants from the aquatic environments. As illustrated in Fig. 1S, two cylindrical MPBR reactors made of plexiglas (diameter = 20 cm, height = 30 cm, freeboard = 5 cm) were used. Total and working volumes of the reactor were 9.4 and 5 L, respectively. Solid carriers were put into the main reactor for microalgae to attach on. 60% of the reactor's volume was filled with the prepared media. The properties of the biofilm carriers included: size of the carriers: 3 cm × 0.5 cm, weight of each carrier/g: 0.17, and shapes of the carriers: tied to be bowknot. The solid–liquid separator was a polyvinylidene fluoride (PVDF), hollow-fiber, microfilter membrane (MF) module, submerged in the middle of reactors; PVDF membrane (average pore size, 0.1 µm) was also used. The effective surface area was 0.043 m^2, and the maximum flux from the membrane was equal to 20 L/m^2 h. Suction pumps, operating in a 3 min on/12 min off cycle, were used to withdraw the membrane permeate. Lighting was provided by 2 red/blue LED lamps (ratio, 1/4; power, 9 w). During the experiments, the highest light intensity was nearly 100 µmol photons/m^2/s on the reactor surface. These lamps were located on the side walls (at a distance of 5 cm) of the photobioreactors and were used 12:12 light: dark cycle. An air compressor was used to provide aeration and mixing effects (0.04% of the used air contained CO_2 for aeration). A diffuser was installed on the bottom of the bioreactors. Aeration rate was 4–5 L/h. Peristaltic pump was applied for injection of influent flow. The transmembrane pressure (TMP) was continuously monitored when the membrane flow was set at a maximum level and whenever the amount of TMP exceeded the recommended maximum permissible levels (30 kpa), the membrane module was removed from the systems for physical washing and cleaning. The membrane module was washed using distilled water for 30 min and was submerged again in the photobioreactors. Initial MPBRs seeding was prepared by the microalgal seed collected from the facultative lagoon located in Foladshahr, Isfahan Province, Iran, with the initial biomass concentration of 53.74 ± 6.28 mg/L (dry weight), which was used for more than 100 days at ambient temperatures (i.e. 26 ± 3 °C). The methods of continuous cultivation in MPBRs were also applied according to a study by Zhuang et al. (2014). The MPBRs reactor was also fed and tested with real effluent secondary wastewater (Table 1). Before entering the real secondary effluent into the system, pre-treatment was performed on it, that is, the secondary effluent was allowed to settle during the night and then, the upper layer of the liquid was used as an influent to the system. Characteristics of the real effluent secondary wastewater and the pre-treated wastewater are presented in Table 1. Although the influent wastewater was completely homogenous, a small submerged pump was