Water Research 106 (2016) 539–549

Contents lists available at ScienceDirect

Water Research

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

Microalgae recycling improves biomass recovery from wastewater treatment high rate algal ponds

Raquel Gutiérrez [a], Ivet Ferrer [a], Andrés González-Molina [b], Humbert Salvadó [b], Joan García [a], Enrica Uggetti [a, *]

[a] GEMMA – Environmental Engineering and Microbiology Research Group, Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya·BarcelonaTech, c/ Jordi Girona 1-3, Building D1, E-08034, Barcelona, Spain
[b] Department of Animal Biology, Faculty of Biology, University of Barcelona, Av. Diagonal 645, Barcelona, Spain

ARTICLE INFO

Article history:
Received 17 June 2016
Received in revised form
13 October 2016
Accepted 17 October 2016
Available online 18 October 2016

Keywords:
Bioflocculation
Biomass recovery
Microalgae species selection
Microalgal biomass production
Harvesting

ABSTRACT

Microalgal biomass harvesting by inducing spontaneous flocculation (bioflocculation) sets an attractive approach, since neither chemicals nor energy are needed. Indeed, bioflocculation may be promoted by recycling part of the harvested microalgal biomass to the photobioreactor in order to increase the predominance of rapidly settling microalgae species. The aim of the present study was to improve the recovery of microalgal biomass produced in wastewater treatment high rate algal ponds (HRAPs) by recycling part of the harvested microalgal biomass. The recirculation of 2% and 10% (dry weight) of the HRAPs microalgal biomass was tested over one year in an experimental HRAP treating real urban wastewater. Results indicated that biomass recycling had a positive effect on the harvesting efficiency, obtaining higher biomass recovery in the HRAP with recycling (R-HRAP) (92–94%) than in the control HRAP without recycling (C-HRAP) (75–89%). Microalgal biomass production was similar in both systems, ranging between 3.3 and 25.8 g TSS/m^2d, depending on the weather conditions. Concerning the microalgae species, *Chlorella* sp. was dominant overall the experimental period in both HRAPs (abundance >60%). However, when the recycling rate was increased to 10%, *Chlorella* sp. dominance decreased from 97.6 to 88.1%; while increasing the abundance of rapidly settling species such as *Stigeoclonium* sp. (16.8%, only present in the HRAP with biomass recycling) and diatoms (from 0.7 to 7.3%). Concerning the secondary treatment of the HRAPs, high removals of COD (80%) and N-NH_4^+ (97%) were found in both HRAPs. Moreover, by increasing the biomass recovery in the R-HRAP the effluent total suspended solids (TSS) concentration was decreased to less than 35 mg/L, meeting effluent quality requirements for discharge. This study shows that microalgal biomass recycling (10% dry weight) increases biomass recovery up to 94% by selecting the most rapidly settling microalgae species without compromising the biomass production and improving the wastewater treatment in terms of TSS removal.

1. Introduction

In recent years, much attention has been paid to microalgae-based systems for wastewater treatment and biomass production like high rate algal ponds (HRAPs). In fact, microalgal biomass grown as a by-product of wastewater treatment is nowadays considered as a cost-effective feedstock for bioenergy production. Despite bioenergy production from microalgae has well-known advantages in front of other biomass sources (i.e. fast growth rates and lack of competence for agricultural land or water), each step of the process from microalgae production to bioenergy conversion still has to be improved in order to reduce the operating costs of the entire process (Mehrabadi et al., 2015).

Specifically, current biomass harvesting techniques increase the cost of microalgae production, representing about 20–30% of the total cost (Molina-Grima et al., 2003; Zittelli et al., 2006). Recently, life cycle assessments and cost analysis of different harvesting techniques have been conducted to assess the cost-efficiency and environmental impact of the most common harvesting techniques (Udom et al., 2013). Methods commonly employed include the addition of chemicals or the use of mechanical equipment that increase costs (e.g. flocculation induced by chemical addition,

* Corresponding author.
E-mail address: enrica.uggetti@upc.edu (E. Uggetti).

http://dx.doi.org/10.1016/j.watres.2016.10.039
0043-1354/

filtration, centrifugation, sonication, electro-flocculation). In wastewater treatment, gravity sedimentation is the most common solids separation method, used to clarify large volumes of treated wastewater with reasonable costs (<5% of the total cost) (Metcalf and Eddy, 2003). The biomass grown in HRAPs for wastewater treatment is constituted by mixed populations of microalgae and bacteria which form spontaneous flocs (diameter 50–200 μm) that can partially settle by gravity without chemicals or energy addition (García et al., 2000; Park et al., 2011a; Valigore et al., 2012). Indeed, inside these flocs, microorganisms interaction provides natural occurring processes inducing their spontaneous flocculation (Salim et al., 2011; Golueke and Oswald, 1970).

For these reasons, in the last years a niche of research of harvesting techniques has focused on the optimization of spontaneous flocculation and gravity sedimentation (Van Den Hende et al., 2011; González-Fernández and Ballesteros, 2013). Different methods and strategies to improve microalgal harvesting have shown promising results regarding spontaneous flocculation. Some of these methods are the coprecipitation with ions at high pH (autoflocculation) and release of extracellular polymeric substances, or microalgae-bacteria interaction (bioflocculation) (González-Fernández and Ballesteros, 2013; Wan et al., 2014). A recently developed strategy consists in promoting the dominance of rapidly settling microalgae species by recycling a small part of the biomass harvested in gravity settlers (Park et al., 2011b). Thus, species that can settle easily are selected competitively against poorly settling species.

Following this promising approach, the aim of the present study was to enhance microalgal biomass harvesting efficiency by recycling an increasing amount of harvested biomass and to determine its effect on biomass production, microalgae species evolution and wastewater treatment performance. Recycling rates of 2% and 10% (dry weight) of the microalgal biomass grown in the HRAPs were tested in order to improve the spontaneous flocculation of algae-bacteria biomass in experimental HRAPs treating real urban wastewater. Harvesting efficiency results were evaluated in terms of biomass recovery and microalgal biomass settling velocities distribution.

2. Material and methods

2.1. Experimental microalgae-based wastewater treatment system

Two experimental HRAPs located outdoors at the facilities of the Environmental Engineering and Microbiology Research Group (GEMMA) of the Universitat Politècnica de Catalunya·BarcelonaTech (Barcelona, Spain) were used. These HRAPs were continuously operated since 2010 (Passos et al., 2015). For the purpose of this research, the HRAPs were monitored over one year (from March 2014 to March 2015). Raw urban wastewater from a nearby municipal sewer was daily pumped to a homogenisation tank (volume of 1.2 m^3) and uninterruptedly pumped to a primary settler with a useful volume of 7 L, a surface area of 0.0255 m^2 and a hydraulic retention time (HRT) in the range of 0.7–1.4 h. The primary settler effluent (from now on referred to as primary effluent) was discharged into both HRAPs by means of two peristaltic pumps. Both HRAPs operated at the same HRT during the whole experimental period. As suggested by García et al. (2000), the theoretical HRT was modified over the year (8, 6 and 4 days) by regulating the flow rates (120, 78.5 and 60 L/d for 4, 6 and 8 days of HRT, respectively) in accordance with the weather conditions (i.e. solar radiation and temperature). In fact, these systems require longer HRT in cold weather conditions with low solar radiation in order to accomplish wastewater treatment and meet effluent quality requirements for discharge.

Each HRAP, built in PVC, had a surface area of 1.54 m^2, 0.3 m of water depth and a useful volume of 0.47 m^3. Continuous stirring of the mixed liquor avoided biomass sedimentation and assured microalgae contact with sunlight. This was achieved by means of two paddle-wheels driven by an engine (5 rpm) reaching a flow velocity of 10 cm/s in the mixed liquor. Biomass growing in the HRAPs was harvested in two secondary settlers (one per each HRAP) with a useful volume of 3.1 L, a surface area of 0.013 m^2 and a critical settling velocity of 0.4, 0.25 and 0.2 m/h (HRT of 0.6, 1 and 1.2 h, respectively) depending on the HRT of the HRAPs. Around 1–1.5 L of harvested biomass with a total solids concentration between 1 and 2% (w/w) (depending on the period of the year) were purged from each settler every weekday.

2.2. Biomass recycling

In order to evaluate the influence of biomass recycling on the harvesting efficiency, microalgal biomass production and wastewater treatment, biomass recycling was set-up in one HRAP, while the other one was used as a control (from now on referred to as R-HRAP and C-HRAP, respectively). Fig. 1 shows a schematic diagram of the process in the R-HRAP line. In a previous study by Park et al. (2011b), a constant volume of 1 L of harvested microalgal biomass was daily recycled to a 8 m^3 HRAP. In this previous study, the constant recirculation volume applied did not take into account the variation of the solids concentration in the HRAP mixed liquor. From the data presented by Park et al. (2011b), a recycling rate between 2 and 16% (dry weight) of the HRAP microalgal biomass was inferred. Taking this range of values as reference, two different recycling rates (2% and 10% dry weight) were tested in the present study, corresponding to a variable recycling flow rate. The recycling flow rate was calculated weekly following Eq. (1).

$$V_R = \frac{Recycling\ rate^{*}(TSS_{HRAP}{*}V)}{TSS_{settler}} \quad (1)$$

where V_R is the volume recycled daily (L); TSS_{HRAP} is the mixed liquor total suspended solids concentration inside the HRAP (mg/L); $TSS_{Settler}$ is the total suspended solids concentration of the biomass harvested in the secondary settler (mg/L) and V is the HRAP volume (L).

Due to biomass recycling, in the R-HRAP the solids retention time (SRT) was higher than the HRT, while the SRT and HRT were identical in the C-HRAP. The SRT of the R-HRAP was calculated by Eq. (2) according to Metcalf and Eddy (2003).

$$SRT = \frac{V{*}TSS_{HRAP}}{(Q - Q_E + Q_P){*}TSS_{HRAP} - Q_R{*}TSS_{Settler}} \quad (2)$$

where Q is the primary effluent flow rate (L/d); Q_E is the evaporation rate (L/d) and Q_P is the precipitation rate (L/d); Q_R is the recycled flow rate (L/d); TSS_{HRAP} is the mixed liquor total suspended solids concentration inside the HRAP (mg/L); $TSS_{Settler}$ is the total suspended solids concentration of the biomass harvested in the secondary settler (mg/L) and V is the total volume of the HRAP (L).

The evaporation rate was calculated following Eq. (3).

$$Q_E = \frac{E_p A}{7} \quad (3)$$

where A is the surface area of the HRAP (m^3) and E_p is the potential evaporation between weekly samples (mm) which was calculated from Turc's formula (Eq. (4)).