Chemical Engineering Journal 265 (2015) 239–248

Contents lists available at ScienceDirect

Chemical Engineering Journal

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

Influence of pH and CO_2 source on the performance of microalgae-based secondary domestic wastewater treatment in outdoors pilot raceways

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HIGHLIGHTS

- Effect of pH on wastewater treatment and biomass productivity/composition was null.
- CO_2 from flue gas supported a superior wastewater treatment performance.
- Carbon, nutrients and *E. coli* were efficiently removed from domestic wastewater.
- Maximum biomass productivity of 17 ± 1 $gm^{-2}d^{-1}$ was recorded in the outdoor pilot RWs.

ARTICLE INFO

Article history:
Received 9 October 2014
Received in revised form 9 December 2014
Accepted 13 December 2014
Available online 19 December 2014

Keywords:
Algal-bacterial symbiosis
Biological wastewater treatment
Flue gas
Microalgae biomass composition
Microalgae biomass production

ABSTRACT

The influence of pH (7, 8 and 9) and CO_2 source (pure CO_2 or CO_2 from flue gas) on both the performance of secondary domestic wastewater treatment and biomass productivity and composition in three outdoors pilot raceways was evaluated for 6 months. Average COD, TN, TP and *Escherichia coli* removal efficiencies of 84 ± 7%, 79 ± 14%, 57 ± 12% and 93 ± 7%, respectively, were recorded. The influence of pH on wastewater treatment was negligible, while the supply of CO_2 from flue gas supported higher COD, TOC and TP removals. Biomass productivities ranged from 4 ± 0 g m^{-2} d^{-1} in December to 17 ± 1 g m^{-2} d^{-1} in July. The highest C, N and P biomass contents (64.8%, 12.6% and 2.4%, respectively) were recorded when flue gas was supplied. Finally, while the protein content in the biomass remained constant (38.2 ± 3.3%), the lipid and carbohydrate contents ranged from 5.8% to 23.0% and from 38.0% to 61.2%, respectively.

1. Introduction

Wastewater management represents an increasing concern worldwide as a result of the exponential human population increase and the rapid industrialization since the mid-20th century. The uncontrolled disposal of domestic and industrial wastewaters into the environment causes severe pollution problems such as eutrophication or oxygen depletion in lakes and rivers, which makes wastewater treatment mandatory [1]. Unfortunately, conventional wastewater treatment technologies present some techno-economic limitations [2]. For instance, process aeration represents 45–75% of the total operation costs in an activated sludge wastewater treatment plant (WWTP) [3], while anaerobic digestion entails a poor nutrient removal [4]. In this context, microalgal-bacterial processes constitute a sustainable and cost-effective alternative to conventional technologies due to their free oxygenation potential and efficient nutrient removal [5]. This green biotechnology is characterized by the oxidation of the organic pollutants present in the wastewater to CO_2 by heterotrophs and by the assimilation of nutrients as a valuable algal-bacterial biomass, which can be further used as a biofertilizer and/or as a feedstock for biofuel production [6,7]. As a result of CO_2 fixation in the presence of light, microalgae photosynthetically provide the O_2 needed by heterotrophs and nitrifiers for the oxidation of organic pollutants and NH_4^+ [8].

Microalgae-based processes were first implemented in the mid 1950s in California for domestic wastewater treatment in algal ponds called raceways (RWs) [9]. RWs are currently the most economic photobioreactor configuration for microalgae cultivation, despite their lower algal biomass productivities when compared to closed photobioreactors [10]. RWs consist of shallow ponds

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http://dx.doi.org/10.1016/j.cej.2014.12.059
1385-8947/

(0.1–0.4 m deep) divided into two or four water channels in order to allow liquid mixing and circulation, which is often provided by paddlewheel mechanical agitation [11]. Since their early applications, RWs have supported a cost-effective organic matter and nutrient removal from domestic, industrial and livestock wastewaters [2,12,13]. However, the low C/N/P ratio in most wastewaters, compared to the algal-bacterial biomass composition ratio (≈100/18/2), often limits the efficiency of nutrient removal in microalgae-based wastewater treatment processes due to a carbon deficiency [9,14,15]. In this regard, an external CO_2 addition into the mixed liquor could enhance algal-bacterial biomass productivities and consequently the recovery of nutrients from wastewaters [16]. CO_2 addition would also prevent the rise in pH in the mixed liquor of the RWs mediated by photosynthetic activity, and therefore mitigate nitrogen losses by N-NH_3 stripping and phosphorus precipitation [1,17]. However, despite the potential of this synergistic process integration, the number of outdoors studies assessing at semi-industrial scale the performance of wastewater treatment supported by CO_2 addition is scarce, with the few studies available mainly focused on tertiary wastewater treatment [14,16].

The present work assessed the performance of three outdoors semi-industrial RWs operated in parallel during secondary domestic wastewater treatment for 6 months (July–December) at three different pHs (7, 8 and 9) controlled by the addition of pure CO_2 and CO_2 from real flue gas. The operation of the RWs was also monitored without pH control in order to evaluate the reproducibility of process performance and to serve as control.

2. Materials and methods

2.1. Microorganisms

The RWs were inoculated with *Scenedesmus* sp. previously cultivated in an outdoors thin layer RW and with activated sludge from the WWTP of El Ejido (Almería, Spain) at total suspended solid (TSS) concentrations of 2500 and 4500 mg L^{-1}, respectively. Under the particular environmental conditions of Almería, *Scenedesmus* has been consistently shown as the dominant microalga species, which supports the selection of this microalga for the inoculation of our raceways [10]. In addition, *Scenedesmus* has been also consistently reported as a microalga species commonly found in photobioreactors treating domestic wastewater [18] (Photograph 2a, Supplementary material).

2.2. Experimental set-up

Experiments were conducted in three outdoor raceways (RW1, RW2 and RW3) located at Estación Experimental Las Palmerillas, property of Fundación CAJAMAR (Almería, Spain) (Fig. 1a; Photograph 2b and 2c in Supplementary data). RW1, RW2 and RW3 consisted of three polypropylene algal ponds of two 6-m length channels, 0.6-m width connected by 180° bends at each end, with 8.33 m^2 of illuminated surface and 10 cm of depth. Guide vanes made of polypropylene were placed in the bends of the photobioreactors. The total working volume in RW1, RW2 and RW3 was 700,

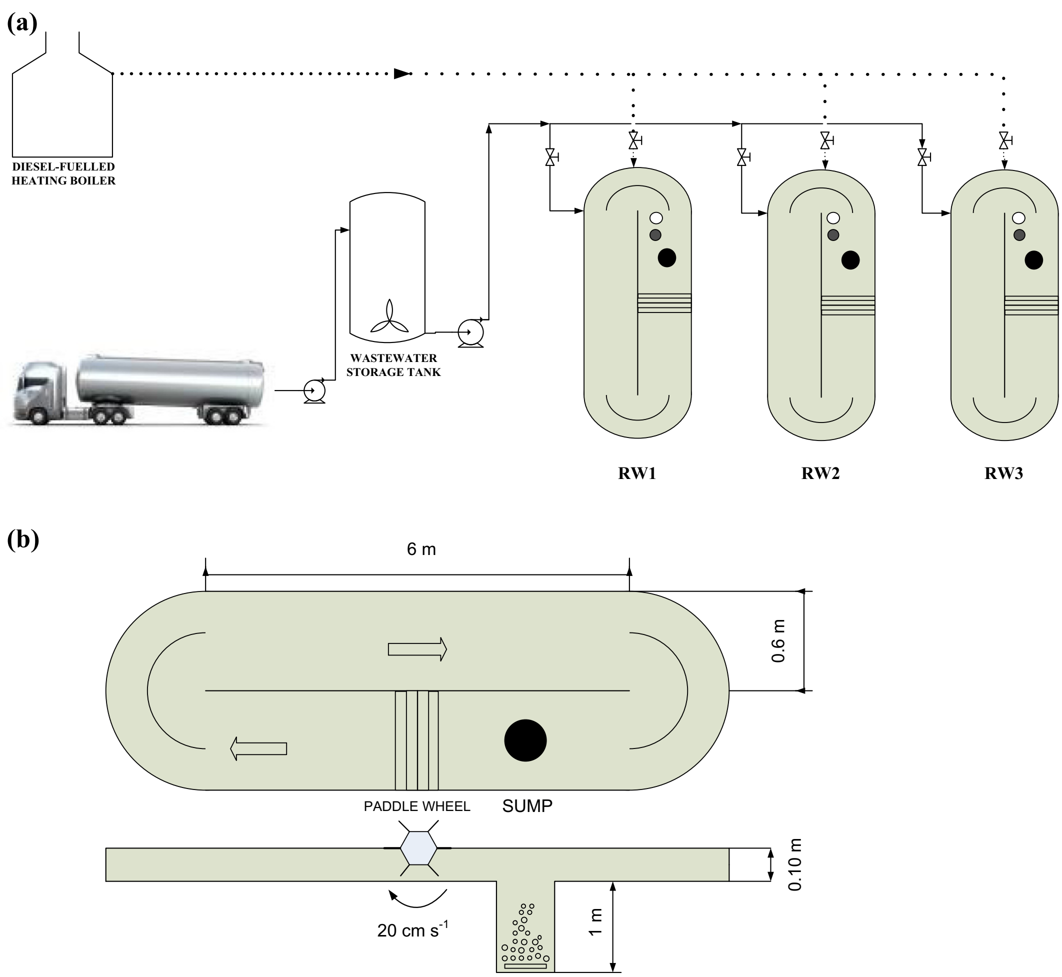

Fig. 1. (a) Schematic of the three raceway photobioreactors. White circles in the RWs represent pH sensor, while grey circles refer to the sensors of dissolved oxygen, temperature, and CO_2 composition. Continuous and discontinuous lines indicate domestic wastewater and CO_2 distribution, respectively. (b) Schematic of a raceway with common dimensions, paddlewheel and sump (black circle).