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Integrating microalgae tertiary treatment into activated sludge systems for energy and nutrients recovery from wastewater

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ABSTRACT

In this study, microalgae digestate and secondary effluent were used to grow microalgae in a tertiary wastewater treatment, and then, the biomass was co-digested for biogas generation. A 30 L closed-photobioreactor was used for microalgae cultivation. The biomass, mainly composed by *Scenedesmus* sp., reached and maintained a concentration of 1.1 gTSS/L during 30 days. A complete removal of N-NH_4^+ and P-PO_4^{3-} and high nitrates and organic matter removals were achieved (58% N-NO_3^- and 70% COD) with 8 d of HRT. The potential biogas production of the cultivated microalgae was determined in batch tests. To improve their biodegradability, a novel method combining their co-digestion with activated sludge after a simultaneous autohydrolysis co-pretreatment was evaluated. After the co-pretreatment, the methane yield increased by 130%. Thus, integrating microalgae tertiary treatment into activated sludge systems is a promising and feasible solution to recover energy and nutrients from waste, improving wastewater treatment plants sustainability.

1. Introduction

Until now, wastewater treatment plants (WWTPs) were mainly conceived for removing contaminants and organic matter, and were designed and managed to protect human and environmental health (Muga and Mihelcic, 2008). However, the increasing water scarcity forces the need for new technological solutions with low cost and low energy demand (Chisti, 2008). To transform a conventional wastewater treatment system into a self-sustainable process it is necessary to shift from the current model towards a new one in which wastewater treatment systems will become a low energy processing industry, able to generate marketable products rather than wastes. For this reason, special efforts have been made recently to increase energy and resource recovery from wastewater by producing valuable byproducts (e.g. biofuels) from WWTPs.

Under this scenario, nature-based treatment solutions, such as microalgae-based systems, are conceived as a breakthrough to a new model for wastewater treatment (Pittman et al., 2011). Indeed, such systems are able to reuse nutrients from wastewater and other wastes (i.e. digestate from anaerobic digestion) in order to grow microalgae biomass which can be used as bioenergy feedstock (Uggetti et al., 2014a). However, the alternative of recycling microalgae digestate has been poorly explored. The main concern in the use of digestate as nutrient for microalgae growth is the elevated ammonium content. Though, this inconvenience may be solved by diluting it with another low strength waste effluent (i.e. secondary effluent from wastewater treatment).

Considering small-medium conventional WWTPs based on the activated sludge process with anaerobic digestion for waste activated sludge (WAS) treatment, a microalgae photobioreactor (PBR) could be introduced as a tertiary treatment in order to improve the treated water quality and increase the biogas production (Fig. 1). Indeed, the microalgae biomass produced in the PBR could be co-digested with waste activated sludge from the conventional plant. In such a case, their co-digestion could improve the methane productivity and the hydrolysis efficiency compared to each substrate mono-digestion, increasing the bioenergy recovery efficiency of the plant (Zhen et al., 2016). In fact, recent investigation has reported higher methane yield and/or rate when microalgae and WAS are co-digested (Beltran et al., 2016; Neumann et al., 2015). Besides, WAS has inherent enzymes inside its extracellular polymeric substances (EPS) which are released after a thermal pretreatment at 55 °C resulting in autohydrolysis of WAS (Carvajal et al., 2013). Hence, the co-pretreatment and subsequent co-digestion of microalgae and WAS may improve the hydrolysis. Moreover, the digestate from the anaerobic digestion could be reused as a source of nutrients for microalgae biomass growth together with the

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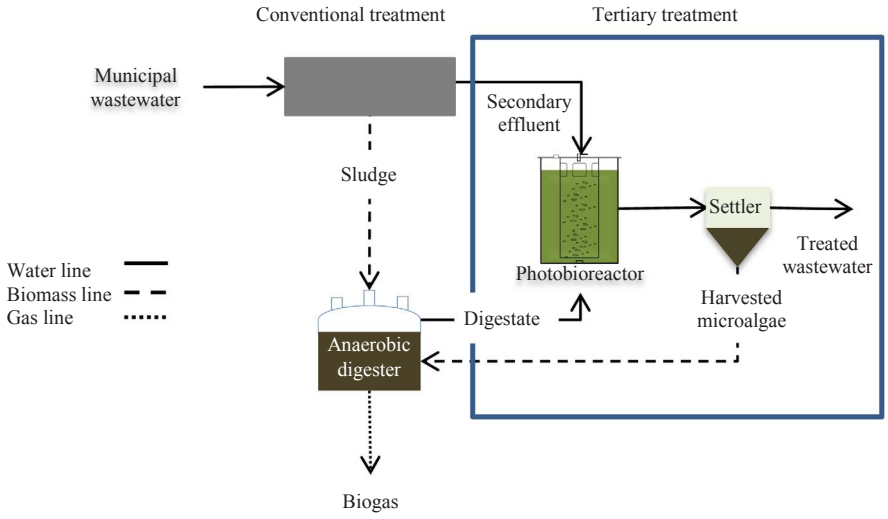

Fig. 1. General scheme of the system proposed in this study.

secondary effluent. In this way, the quality of treated wastewater would be improved, as compared to conventional biological systems, and the digestate would be treated while increasing the concentration of nutrients for microalgae growth.

Following the scheme proposed in Fig. 1, this article addresses a novel approach in the field of wastewater treatment. Previous studies focused on microalgae production for biogas production (i.e., Passos et al., 2015, 2013; Passos and Ferrer, 2014), were addressed to treat urban wastewater by means of high rate algal ponds as a secondary treatment. Differently, this study proposes an integrated system of activated sludge and microalgae tertiary treatment for nutrients and bioenergy recovery from wastewater. Thus, the objectives of this research were: 1) to study the microalgal biomass production treating the secondary wastewater effluent and digestate; and 2) to quantify the methane yield of harvested microalgae biomass co-digested with waste activated sludge after an autohydrolysis pretreatment.

2. Methodology

2.1. Experimental set-up

Experiments were carried out at the laboratory of the GEMMA Research Group (Barcelona, Spain). Microalgae were grown in a closed cylindrical photobioreactor (30 L). The PBR was fed with microalgae uncentrifuged digestate diluted in secondary effluent from a pilot high rate algal pond (HRAP) treating municipal wastewater. The latter came from a pilot system treating municipal wastewater which comprised a primary settler, a high rate algal pond (HRAP) and a secondary settler (Gutiérrez et al., 2016). The digestate was obtained from lab-scale anaerobic digesters (1.5 L) that produced biogas from microalgae biomass harvested from the HRAP. A detailed description of the anaerobic digesters and HRAP may be found in Passos et al. (2015).

2.2. Photobioreactor operation

A mixed microalgae culture obtained from a pilot high rate algal pond was utilized as inoculum to start-up the photobioreactor. This inoculum consisted of a community of microalgae, bacteria, protozoa and small metazoan, specifically dominated by the microalgae genus *Chlorella* sp., *Scenedesmus* sp. and *Stigeoclonium* sp. The closed photobioreactor was located indoors and consisted of a cylindrical vessel made of polymethyl methacrylate with a working volume of 30 L. The mixed liquor was stirred by means of an air sparger placed at the bottom of the photobioreactor, at a flow of 10 L/min and a pressure of 0.034 MPa using a 105 W air compressor (model ACQ-012, JAD, China). The photobioreactor design and operation characteristics may be found elsewhere (Arias et al., 2017). The culture in the photobioreactor was in continuous operation alternating light:dark periods of 12 h. During the illuminance period, light was supplied by an external lamp (600 W, Sunmaster, USA) placed at 80 cm in front of the photobioreactor, providing 19,000 lux (289 μmol/m^2s). The temperature of the culture along the experimental period ranged from 25 to 29 °C.

The photobioreactor was fed once a day (semi-continuously) with microalgae digestate diluted in secondary effluent at a ratio of 1:50, and operated at 8 days of hydraulic retention time (HRT) and solids retention time (SRT). The dilution ratio of 1:50 was performed in order to decrease the ammonium ($N\text{-}NH_4^+$) content to concentrations below 10 mg/L in the photobioreactor influent. The physico-chemical characterization of the digestate and secondary effluent used as influent for microalgae growth in the photobioreactor is shown in Table 1.

2.3. Biochemical methane potential assay

2.3.1. Substrates and inoculum

The microalgae biomass used in the biochemical methane potential (BMP) assays was collected from the photobioreactor effluent after stable operation. At the time, the microalgae biomass was clearly dominated by *Scenedesmus* sp. Harvested biomass was settled for 1 day,

Table 1
Composition of the wastewater used as photobioreactor feedstock.

Parameter	Digestate	Secondary effluent	Photobioreactor influent[a]
pH	–	–	7.9 ± 0.3
TSS (g/L)	13.4 ± 8.5	[b]	0.26 ± 0.17
VSS (g/L)	12.3 ± 6.5	[b]	0.24 ± 0.13
Alkalinity (mg $CaCO_3$/L)	–	–	153 ± 38.4
CODs (mg O_2/L)	122.8 ± 25.9	18.3 ± 5.5	141.1 ± 36.1
$N\text{-}NH_4^+$ (mg/L)	459 ± 166.5	0.21 ± 0.84	9.17 ± 3.33
$N\text{-}NO_2^-$ (mg/L)	< LOD[c]	1.44 ± 0.69	1.53 ± 0.91
$N\text{-}NO_3^-$ (mg/L)	< LOD[c]	15.94 ± 4.94	15.94 ± 4.94
TIN	–	–	26.64 ± 3.06
$P\text{-}PO_4^{3-}$ (mg/L)	< LOD[c]	2.18 ± 0.87	2.18 ± 0.87

TIN: Total Inorganic Nitrogen.
[a] Photobioreactor influent prepared by diluting the digestate in secondary effluent (1:50 ratio).
[b] TSS and VSS in the secondary effluent presented values < 0.03 g L^{-1}.
[c] LOD: Limit of Detection.