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Research article

Energetic valorization of algal biomass in a hybrid anaerobic reactor

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ABSTRACT

This study evaluated the operation of a hybrid anaerobic reactor fed with algal biomass cultivated in effluent from the brewery industry. Three stages of operation were distinguished during the 72 days of semi-continuous functioning of the reactor: Stage 1 (S1), in which algal biomass was used as substrate; Stage 2 (S2), in which 10% (v/v) of the algal biomass was substituted by olive mill wastewater (OMW); and Stage 3 (S3), in which algal biomass was heat pre-treated. During S1, a loss of solids was observed, with an increment of organic matter in the outlet. The substitution of 10% of the volume of algal biomass by OMW tripled the methane productivity obtained in the previous stage by digestion of pure algal biomass. Heat pre-treatment was not efficient in rupturing the cell wall, and consequently did not have any effect on the increase in biogas production. The complementarity of substrates in the assessed conditions led to better results than the pre-treatment of the algal biomass.

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1. Introduction

One of the most important processes for converting biomass into energy is anaerobic digestion, which consists of the biochemical conversion of organic matter into biogas. Anaerobic digestion technology presents great applicability for a wide range of substrates and is used all over the world. Biogas is capable of producing 20–300 kWh of net energy per tonne of substrate (European Commission, 2005) and the residual biomass after anaerobic digestion still contains mineralized nutrients, so it can be used as organic fertilizer after the energy production process (Vergara-Fernandez et al., 2008; Ward et al., 2008).

The capacity of microalgae to adapt and survive in a wide range of environments is enormous and their cultivation can be associated with the objectives of wastewater treatment and energy production. More recently, microalgae have emerged as a new substrate for the production of biofuels through anaerobic digestion. This potential for biogas production can be associated with the low lipid content of algae biomass grown in wastewaters and also with the possibility to use humid biomass, saving energetic and economical resources from the drying process.

However, limitations arising from the algal biomass substrate are still currently described. The greater complexities of the anaerobic digestion of the algal biomass are reported as being the low algae cell wall digestibility and the inhibition of the process by the presence of ammonia due to high protein content (Mussgnug et al., 2010; Sialve et al., 2009). Advances still need to be made to consolidate the process and overcome those limitations. Therefore, studies focus on biomass co-digestion (Wang et al., 2013; Ramos-Suárez and Carreras, 2014) and pré-treatment methods (Alzate et al., 2012; Passos et al., 2013; Zhao et al., 2014).

The type of reactor selected to perform the anaerobic digestion is also an important factor in achieving good performance and economic viability of the process. Regarding anaerobic reactor configuration for algal biomass digestion, the performance of the continuous stirred tank reactor is still limited, but probably is the most used reactor type for this substrate digestion. A strategy that may be applied in order to overcome algal cell wall resistance, besides pre-treatments, is the use of more suitable reactors. The disassociation of hydraulic retention time and solids retention time may be a potential strategy (González-Fernández et al., 2015).

The hybrid anaerobic reactor is an ascending-flow fixed-bed reactor that combines the positive aspects of the up flow anaerobic sludge blanket (UASB) reactor and the anaerobic filter, namely the greater tolerance to high organic loads and the guarantee of lower losses of suspended solids. Consequently, the efficiency of the reactor increases as the treated effluent reaches a better quality

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(Ayati and Ganjidoust, 2006; El-Gohary et al., 2009).

Besides reactor configuration, there are few studies regarding continuous feeding reactors (Prajapati et al., 2013). According to González-Fernández et al. (2015), data obtained in batch-mode assays can provide some guidance, but assessment of the benefits of pre-treatments applied to semi-continuous operations is highly recommended in order to deepen the studies on the performance of anaerobic microorganisms when fed with pre-treated algal biomass. Moreover, use of complex biomass composed not only by microalgae and grown in wastewater system is scarce, although its importance on the sustainability of bioenergy production is highly recognized.

The present study aimed at assessing the operation and monitoring of a hybrid anaerobic reactor semi-continuously fed with algal biomass cultivated in effluent from a brewery industry. Biogas production and organic matter degradation efficiency were monitored throughout three operation stages, characterized by the use of complementary substrate to the algal biomass and application of a heat pre-treatment for the rupture of the microalgae cell wall.

2. Materials and methods

2.1. Substrates

2.1.1. Algal biomass

Wet algal biomass was used as one of the substrates of the hybrid anaerobic reactor (Table 1).

The algal biomass was cultivated in bubble column reactors kept indoors under artificial illumination (fluorescent lamps) and with the addition of air. A total of 30 batch mode reactors (5 L each) were filled with inoculum of the species *Scenedesmus obliquus* (ACOI 204/07, University of Coimbra – Culture Collection, Portugal). The cultivation medium was an effluent pre-treated in the BIOPAQ®IC anaerobic reactor of a brewery industry. The characterization of such effluent is presented in Table 2.

2.1.2. Olive mill wastewater

Olive mill wastewater (OMW) was used as complementary substrate to the algal biomass to feed the hybrid anaerobic reactor. The OMW was collected in an olive oil production plant equipped with a three-stage extraction process, located in Rio Maior, Portugal. The characterization of such effluent is presented in Table 2.

2.2. Anaerobic digestion: functioning and experimental configuration

2.2.1. Experimental apparatus

The anaerobic digestion experiments were carried out in a hybrid ascending reactor. The reactor (Fig. 1) was designed in transparent acrylic with a total volume of 2.8 L and useful volume of 1.7 L. The fixed bed was filled one third of the height of the reactor and packed with polyethylene net (Marques, 2001). No solid–liquid–gas separation device was installed and there was no substrate recirculation. The reactor was fed semi-continuously, three times per day, at a rate of 0.283 L/day by peristaltic pump (Watson Marlow, 520 Du) at 12 rpm. The reactor was kept at 37 ± 2 °C by circulating water in its outer layer after previous heating in a thermostatic bath. Gas production was measured by a gasometer (Actaris) and the biogas volume produced daily was corrected for standard temperature and pressure (STP) condition (0 °C, 100 kPa). Three points located along the height of the reactor allowed access to different zones: the sludge bed (P3: 7.5 cm), immediately below the filtration zone (P2: 31 cm), and the middle of the filtering bed (P1: 41 cm).

2.2.2. Start-up, inoculation and operation

Prior to operation with algal biomass, the hybrid anaerobic reactor was operated with bovine effluent from confined dairy cattle. After 140 days of operation with bovine effluent, the hybrid

Table 1
Chemical composition of algal biomass used as substrate for the hybrid anaerobic reactor.

Composition		Mean (% dry mass)	Standard deviation
Total lipids		31.6	
	Neutral lipids	25.3	
	Membrane lipids	6.3	
Proteins		36.9	0.6
Ash		28.7	0.1
Carbohydrates		4.3	0.2

Table 2
Characterization of the brewery effluent and olive mill wastewater.

		Brewery effluent	Olive mill wastewater
pH		7.24	4.76
Total COD	g/L	0.63 (17.9)	83.1 (2.4)
TKN	mg/L	120.4 (8.4)	0.47 (0)
$N-NH_3$	mg/L	24.5 (2.1)	ND
TSS	mg/L	515 (55)	31.2 (3.8)
VSS	mg/L	410 (40)	27.6 (3.0)
FSS	mg/L	105 (15)	3.6 (0.8)
PO_4^{-3}	mg/L	41.25	0.74
P_2O_5	mg/L	30.75	0.55
Total phenols	g eq. caffeic acid/L	–	6.7 (0.3)

Mean values and standard deviation in parentheses. Total COD = total chemical oxygen demand; TKN = total Kjeldhal nitrogen; $N-NH_3$ = ammonia nitrogen; TSS = total suspended solids; VSS = volatile suspended solids; FSS = fixed suspended solids; PO_4^{-3} = phosphate; P_2O_5 = phosphorus pentoxide. ND = not detected.

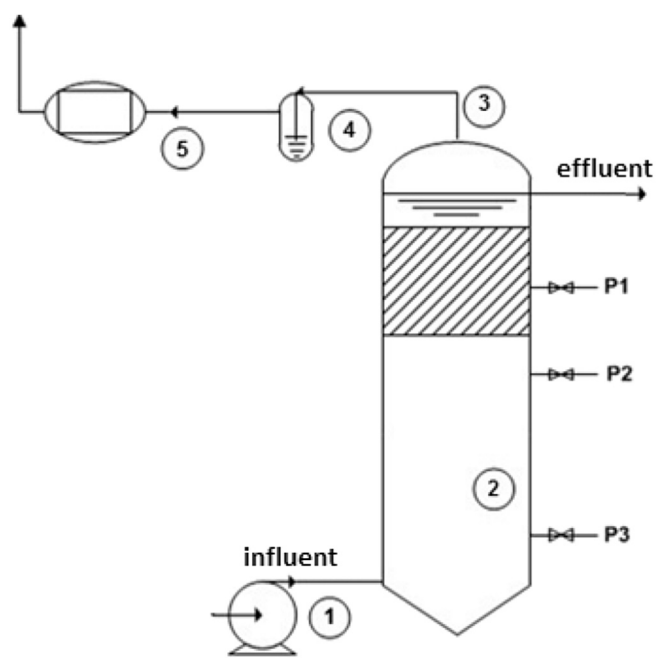

Fig. 1. Experimental scheme of the hybrid anaerobic reactor: (1) peristaltic pump; (2) hybrid reactor; (3) biogas outlet; (4) hydraulic seal; and (5) gasometer. Sampling points: P3: 7.5 cm; P2: 31 cm; P1: 41 cm. Source: Adapted from Gonçalves et al. (2012).

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