Journal of Environmental Management 181 (2016) 48–53

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Water-energy nexus: Anaerobic co-digestion with elephant grass hydrolyzate

A.R. Carvalho [a,*], R. Fragoso [a], J. Gominho [b], A. Saraiva [a], R. Costa [a], E. Duarte [a]

[a] LEAF – Linking Landscape, Environment, Agriculture and Food, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017, Lisboa, Portugal

[b] Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017, Lisboa, Portugal

ARTICLE INFO

Article history:
Received 21 March 2016
Received in revised form
2 June 2016
Accepted 7 June 2016

Keywords:
Anaerobic co-digestion
Sewage sludge
Pennisetum purpureum
Methane yield
Treatment performance

ABSTRACT

The anaerobic co-digestion process in a continuous stirred-tank reactor (CSTR) was carried out under mesophilic conditions (37 ± 0.2 °C). All the trials were performed at a hydraulic retention time (HRT) of 15 days and the AD reactor was daily fed with a mixture of sewage sludge (SS) and elephant grass hydrolyzate (EGH).

In this study, three different trials were assessed, with different mixture proportions of SSSS and EGH: F0 (100:0,v/v), F1 (75:25, v/v) and F2 (50:50, v/v), during 90 days each trial, keeping the organic loading rate (OLR) in a range of 0.94–1.16 g VS L^{-1} day^{-1}.

The experimental results obtained showed that the soluble chemical oxygen demand (SCOD) removal efficiency was around 77% and 86% for trials F1 and F2, respectively. SS co-digestion with EGH enhanced methane yield, leading to an increment between 23% and 38%, in comparison with the reference scenario (F0).

1. Introduction

Anaerobic digestion (AD) is a biological process carried out in the absence of oxygen in which organic matter is metabolized by an assortment of microorganisms with the production of biogas (about 50–75% of methane and 50–25% of carbon dioxide) (Michalska et al., 2015; Mata-Alvarez et al., 2014). This bioconversion process is widely used to treat wastewater sludge, industrial and farm wastes providing volume and mass removal up to 50% from the input material (Shokri, 2011; Di Maria and Micale, 2016). It is considered a renewable energy source because the methane-rich biogas produced is suitable for energy production and can replace the excessive use of fossil fuels. As part of an integrated waste management system, AD contributes to greenhouse gases mitigation avoiding methane emission that would occur if the wastes were sent to landfill (Michalska et al., 2015; Lacovidou et al., 2012).

Different strategies have been proposed to increase biogas production and optimize SS anaerobic digestion (Appels et al., 2008; Peces et al., 2015). SS ranks as the second main substrate for anaerobic co-digestion (AcoD). Historically, AcoD of SS with the organic fraction of municipal solid waste and with agricultural wastes are the most reported co-digestion research (Mata-Alvarez et al., 2014; Peces et al., 2015; Barbanti et al., 2014). The low organic loading rate (OLR) of the SS and the non-used capacity of the wastewater treatment plants digesters, frequently as much as 30%, are the main driving forces behind SS co-digestion (Pavlík et al., 2016; Montusiewicz and Lebiocka, 2011). SS is characterized by relatively low C/N ratio and high buffer capacity (Astals et al., 2013; Silvestre et al., 2011; Kumar et al., 2009), comparing with other possible substrates. Attending to these characteristics, this substrate is able to balance mixtures with co-substrates having high amounts of easily biodegradable organic matter and low alkalinity values (Lacovidou et al., 2012; Dai et al., 2013). The search for economically viable and environmentally sustainable energy supply is becoming a major driving force of current international developments in energy production. Biomass, due to its renewable character and net carbon neutral energy conversion, has been considered a promising energy source (Roda et al., 2016; Reilly et al., 2015). Combining SS with energy non-edible crops lead to positive scenarios for soil properties and nutritional content (Zhang et al., 2011; Zegada-Lizarazu et al., 2010; Blanco-Canqui, 2010). Lignocellulosic biomass, such as agricultural residuals and non-edible crops (e.g. switchgrass (*Panicum virgatum*), miscanthus

* Corresponding author.
E-mail address: anaritacarvalho@isa.ulisboa.pt (A.R. Carvalho).

http://dx.doi.org/10.1016/j.jenvman.2016.06.012
0301-4797/

(*Miscanthus* sinensis) and elephant grass (*Pennisetum purpureum*)), is an abundant resource due the large quantities of accumulated residues from agricultural, forestry, municipal and other activities. Elephant grass (*Pennisetum purpureum*) (EG) is a high yielding tropical C_4 bunchgrass native of Africa. The stalks achieve 3 m high and the biomass yields range between 12 and 150 ton ha^{-1} per year (Xie et al., 2011a). Nowadays this crop is been considered an alternative as feedstock for energy production in different scenarios. Therefore, biomass pre-treatment prior to anaerobic co-digestion is usually required to reduce structural and compositional impediments of lignocellulosic biomass and expose the polymer chains of cellulose and hemicellulose to microbial break down leading to the increase of biomass degradation rate and biogas yield (Michalska et al., 2015; Reilly et al., 2015). Due the complexity and variability of biomass chemical structures, the optimal pre-treatment method and conditions depend on the types of lignocellulose present (Xie et al., 2011b; Hu et al., 2016; Ravidran and Jaiswal, 2016). Thus, biogas production requires a co-substrate rich in sugars in order to promote the C/N ratio (Giuliano et al., 2013) and the biomass used must be thermal and/or chemical pre-treated in order to obtain hydrolysable fractions that can be easily converted (Lacovidou et al., 2012; Kolodziej et al., 2016; Anjum et al., 2016).

Comparing different pre-treatments, the most effective is thermos-chemical procedures once they are easy and shorter time processing, increasing the biogas yield with lower energy consumption, promoting economic feasibility and higher bioconversion yields (Peces et al., 2015; Harris and McCabe, 2015; Hassan et al., 2016). Sodium hydroxide is the most popular base used in alkaline pre-treatment to remove lignin, hemicellulose, and/or cellulose, rendering lignocellulosic biomass more degradable to microbes and enzymes and has been extensively studied to improve biogas yield by increasing hardwood digestibility from 14 to 55% and reducing lignin content from 24–55% to 20% (Kumar et al., 2009; Minmunin et al., 2015). The kinetics of the chemical reaction is associated with the lignin content of biomass materials and promotes a greater solubilisation rate of larger biomolecules, through the improvement of porosity and internal surface area, structural swelling, a decrease in the degree of polymerization and crystallinity, disruption of lignin structure and a breakdown of links between lignin and other polymers (Michalska et al., 2015; Ravidran and Jaiswal, 2016; Harris and McCabe, 2015; Nieves et al., 2011; Zheng et al., 2014; Chen et al., 2012). The application of an alkali pre-treatment leads several advantages and disadvantages. On one hand promotes a high pH on feed mixtures, avoiding the anaerobic digester acidification (Reilly et al., 2015) are more effective on lignin removal (Ravidran and Jaiswal, 2016; Hassan et al., 2016), effective for the removal of hemicelluloses (Sun et al., 2016), causing less sugar degradation (Rabemanolontsoa and Saka, 2016). An important drawback of alkali treatments are the needing of applying high temperature to promote the hydrolysis which increases energy demand and removes part of hemicellulose, causing sugar loss (Rabemanolontsoa and Saka, 2016). Also, in what way the alkali hydrolysis influence further biogas production and the fermentation process (Michalska et al., 2015).

The chemical composition of elephant grass (*Pennisetum purpureum*) showed an important content in holocelluloses (78%) where 45% correspond to α-cellulose (crystalline fraction) and 33% to the hemicelluloses (amorphous fraction). The hemicelluloses fraction can be easily removed by an alkaline pre-treatment and the obtained liquid fraction can be used as co-substrate in AD (Ravidran and Jaiswal, 2016; Oliveira et al., 2012; Reddy et al., 2012).

The main objective of the present study, based on previous research (Oliveira et al., 2012), was to assess the effect of incorporating elephant grass (*Pennisetum purpureum*) as co-substrate, after a mechanical-thermal-chemical pre-treatment to enhance SS methane production.

2. Materials and methods

2.1. Wastewater treatment plant mixed sludge (SS) and elephant grass

The sewage sludge (primary sludge and activated sludge, 40:60 (%) v:v) was collected from a Wastewater Treatment Plant, located in Lisbon (Portugal), handling more than 50 000 m^3 of wastewater daily, corresponding to 210 000 inhabitant's equivalents (IE).

All samples were collected weakly using 5 L plastic containers and characterized on reception at the laboratory. Afterwards, samples were kept under refrigeration at 4 °C to avoid variations on samples characteristics.

The elephant grass (*Pennisetum purpureum*), EG, with about 6 months of age was collected from a pedagogic field (BioEnergISA) installed at ISA campus (Instituto Superior de Agronomia, Lisbon). The material was grinding, dried at 60 °C until no change in weight and disintegrated using a knife mill (Retsch SM2000) with an output sieve of 10 mm × 10 mm before a pre-treatment be applied.

2.2. Analytical methods

SS and EG, feed mixtures and correspondent digestates were characterized in accordance with Standard Methods for the Examination of Water and Wastewater (APHA-American Public Health Association, 2012): pH, electrical conductivity (EC), total solids (TS), volatile solids (VS), total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4^+-N), total phosphorus (TP), total alkalinity (TA) and total organic carbon (TOC).

2.3. EG pre-treatment

The pre-treatment selected in this study was a combination between a mechanical and a thermo-chemical procedure. Chemical pre-treatment included an extraction using 10 g of mechanically pre-treated EG per liter of sodium hydroxide solution (0.5%, v/v) heated at 120 °C and 1.8 bar, during 60 min. The pre-treated mixture was separated by vacuum filtration in two fractions. The liquid fraction obtained in this solid-liquid separation, entitled elephant grass hydrolyzate (EGH) was stored at 4 °C to be used as a co-substrate to feed AD reactor. The solid fraction was dried at 60 °C until constant weight and storage on black plastics bags to future assays.

2.4. Operating procedures and process monitoring

The process efficiency was assessed monitoring in triplicate the pH, EC, TS, VS, VSS TCOD, SCOD, TKN, NH_4^+-N and TP, both in the influent and effluent. Process monitoring included gas production rate (GPR), biogas quality and specific gas production (SGP) on VS basis. GPR was measured daily using a gas meter (Schlumberger, Germany) and biogas quality was determined weekly by an LMSxi Multifunction Gas Analyser (Gas Data, United Kingdom), providing quality results in composition of methane (CH_4) and carbon dioxide (CO_2).

To evaluate the digester stability and its performance, specific energy-loading rate (SELR) was calculated after each steady-state cycle, according to literature. This parameter measure the energy loading relative to the reactor biomass, correlating the organic content used in feed mixtures (TCOD) with VSS inside CSTR (Amador et al., 2012; Panter and Nilsen, 2011).