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Influence of total solids concentration on the anaerobic co-digestion of sugar beet by-products and livestock manures

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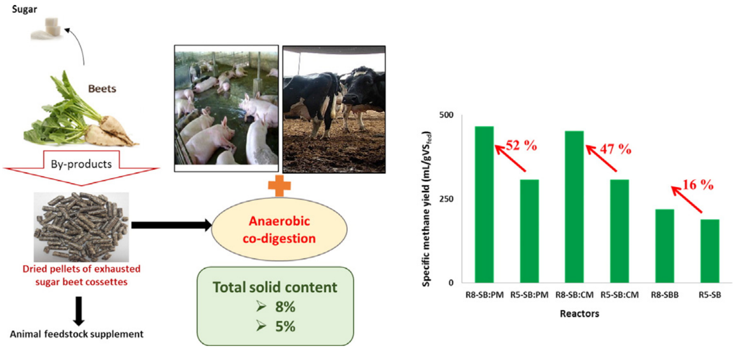
HIGHLIGHTS

- Mesophilic anaerobic digestion of sugar beet byproducts was studied.
- Co-digestion of sugar beet byproducts with two livestock manures was conducted.
- Influence of two total solid contents of 8% and 5% on the process was evaluated.
- Operation at TS content of 8% showed better results than 5% TS.

GRAPHICAL ABSTRACT



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ABSTRACT

A series of batch anaerobic digestion assays were implemented to determine the influence of total solids concentration on the anaerobic digestion of sugar beet by-products and their co-digestion with two kind of livestock manures (pig and cow manures). The two total solid concentrations studied were 8% and 5%. Total solids contents above 8% were not evaluated because of the inappropriate rheological behaviour of sugar beet by-products at these concentrations. The best total solid content tested corresponded to 8%, achieving specific methane yields of 464.3 and 451.4 mL/g VS$_{added}$ for co-digestion with pig manure and cow manure respectively. These data were 1.5 times higher than that obtained for reactors operating with 5% total solids content. For individual digestion of sugar beet by-products, final methane yields operating at 8% were also higher than those measured at 5% total solids concentration. However, in these tests, a large delay in the start of biogas production was registered due to the inhibition caused by the accumulation of volatile fatty acids. No significant differences in the organic matter removal efficiencies were observed for the two total solids contents studied.

1. Introduction

Industrial plants for sugar production from sugar beet generate an enormous amount of by-products consisting mainly in exhausted pulp and molasses. The mixture of both by-products is normally used as a supplement for animal feeding (Hutnan et al., 2000). However, the use of sugar beet by-products (SBB) as biomass resource for renewable energy production presents a great interest due to its high carbonaceous material content, suitable for biogas generation through the anaerobic digestion (AD) technology (Alkaya and Demirer, 2011; Fang et al., 2011; Aboudi et al., 2016; Aboudi et al., 2015). Although SBB constitute an appropriate substrate for the anaerobic digestion process, it may present some limitations due to their deficiency on some nutrients,

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such as nitrogen. Therefore, co-digestion of SBB with livestock manures, which are a source of nitrogen, has shown to be a suitable strategy to enhance biogas production and process stability (Fang et al., 2011; Aboudi et al., 2016; Aboudi et al., 2015; Umetsu et al., 2006; Ohuchi et al., 2014).

With regard to the production costs of a biogas plant, they mainly depend on the energy invested to operate the process, where the principal energy demand corresponds to the heating and mixing of the material contained in the reactors (Brambilla et al., 2013; Björn et al., 2012; Yang et al., 2015). Among the factors influencing the performance of an anaerobic digester, the rheological properties of the substrate play an important role. In this context, several types of wastes (i.e. dry fibrous wastes as SBB) lead to increase the viscosity of the digester and hence, inadequate mixing, break down of stirrers and foaming could be produced (Abbassi-Guendouz et al., 2012; Liotta et al., 2014).

The rheological properties of the medium in the digesters are strongly related to the total solids concentration (Björn et al., 2012; Slatter, 1997). In the literature, two common ranges of total solids concentration have been established for the AD process: wet AD (W-AD; TS ≤ 15%) and solid-state AD (SS-AD; TS > 15%) (Van Soest et al., 1991). However, other authors have defined three ranges, distinguishing wet-AD (TS < 10%), semidry-AD (10% < TS < 15%) and dry-AD (TS > 15%) (Liotta et al., 2014; Li et al., 2011). Nevertheless, it is difficult to correlate the mentioned ranges to the requirements of the process for a specific substrate and hence, a characterization of the physical properties of each substrate is mandatory (APHA, 2005). Ge et al. (2016) reported that the anaerobic digestion of lignocellulosic substrates at high TS content could have a negative impact on the performance of the process due to the following three major reasons:

1- Accumulation of inhibitors (i.e. volatile fatty acids) due to diffusion limitations;
2- Diffusion limitations in the access of microorganisms to substrates and
3- The low water content affecting the metabolism of microorganisms.

In the same way, Chandraa et al. (2012) reported that the water content of an anaerobic digester differs according to the raw material used as feedstock, and it could reach around 90% of the total weight. Hence, an excess of water could decrease the biogas production, while a water defect could lead to acidification and inhibition of the AD process.

Therefore, this study deals with the effect of the total solids concentration on the anaerobic digestion performance of a fibrous lignocellulosic waste, SBB, co-digested with two types of livestock manures.

2. Material and methods

2.1. Substrates and inoculum

SBB (dried pellets of exhausted sugar beet cossettes) employed in this study were provided from a beet-sugar processing facility located at Jerez de la Frontera (Cádiz) in the south of Spain. Pig and cow manures (PM and CM) were used as co-substrates and were collected directly from two semi-intensive livestock farms, located at El Puerto de Santa Maria, in the same county. The farms do not have any system to separate solids and liquids portions of animal excrements and therefore the whole mixture was used. Collected SBB were stored at 4 °C before their use while livestock manures were used the same day they were collected.

Effluent from a mesophilic lab-scale semi-continuous digester, fed with SBB, was used as inoculum (Aboudi et al., 2016).

The characteristics of the SBB, PM, CM and inoculum are presented in Table 1.

2.2. Experimental design and set-up

Batch tests were conducted using a series of 2 L stainless steel bioreactors. A heating plate, located at the base of each reactor, was used to maintain the mesophilic temperature (35 °C). The reactors were covered with a metal wrapper to facilitate the heat transfer and the temperature homogenization in the medium. In addition, each reactor had an independent stirring system (Aboudi et al., 2015).

For the co-digestion tests, the mixing ratio between SBB and livestock manures (PM and CM) was established to obtain a C/N ratio of 18.5 (Aboudi et al., 2015). The inoculum was 50% (weight basis). Two TS contents (8% and 5%) were studied in order to determine the most appropriate TS content for the anaerobic process. TS contents above 8% were not studied, since the rheological characteristics of SBB hindered mixing and homogenization inside the reactors.

Before starting-up, all reactors were sealed and the headspace of each reactor was purged with nitrogen gas for about 5 min to obtain anaerobic conditions. The initial pH of all reactors was measured and adjusted to 7.5 by adding 8 M NaOH, to prevent system failure by acidification.

The nomenclature employed in the reactors is given in the Table 2. All tests were performed in duplicate and the data shown in the paper corresponds to the mean values.

2.3. Analytical methods

Total solids (TS), volatile solids (VS), total and soluble chemical oxygen demands (tCOD, sCOD), dissolved organic carbon (DOC), pH, alkalinity and ammonium were analysed according to the Standard Methods from APHA-AWWA-WPCF (APHA, 2005). For soluble parameters (sCOD, DOC) and volatile fatty acids (VFAs), samples were previously lixiviated for 2 h with deionized water and then filtered through a 0.47 mm filter (Álvarez-Gallego, 2005). Total COD was measured directly from the diluted effluent without any previous filtration and TKN (total Kjeldahl nitrogen) was directly analysed from the dried sample. The dissolved organic carbon (DOC) analysis was carried out in an Analytic-Jena® multi N/C 3100 carbon analyser with a chemiluminescence detector (CLD) according to the combustion-infrared method (5310B) of the Standard Methods (APHA, 2005). The oxidizing gas was oxygen 5.0 at a pressure of 4–6 bars. For VFA analysis, samples previously lixiviated and filtered were filtered again through a 0.22 μm Teflon® filter and analysed with a gas chromatograph (Shimadzu® GC-2010) equipped with a flame ionization detector (FID) and a capillary column filled with Nukol® (diameter of 0.25 μm and 30 m length). Biogas generated during the assays was collected in a 10 L Tedlar® gas bag (SKC) and its volume was measured daily using a high precision drum-type gas meter (Ritter® TG5). The gas composition (CH_4, CO_2, and H_2) was determined by using a gas chromatograph (Shimadzu® GC-2014) with a stainless steel column packed with Carbosieve® SII (diameter of 3.2 mm and 3.0 m length) and a thermal conductivity detector (TCD).

The water holding capacity, which refers to the capacity of SBB to absorb water, was determined according to the method of Boussarsar et al. (2009). The Van Soest method was applied to determine the lignocellulosic content of SBB (cellulose, hemicellulose, lignin) and its chemical fractionation with detergents (neutral detergent fiber-NDF and acid detergent fiber-ADF) (Van Soest et al., 1991).

2.4. Kinetic modelling

The modified Gompertz model has been largely used as a suitable model to describe the production of biogas (methane or hydrogen) in batch systems (Shin et al., 2008; Xie et al., 2017).

In the present paper, a modified Gompertz equation was used to fit the methane production in the reactors, as shown below.

$$M = P_0 + P\,\exp\left[-\exp\left(\frac{eRmax(\lambda - t)}{P} + 1\right)\right]$$

where “M” is the cumulative methane production (L); “P_0” is the small initial methane production observed at the start-up before lag-phase

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